IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

FCI USA, INC. and FCI AMERICAS TECHNOLOGY, INC., Plaintiffs, v. MOLEX INCORPORATED, Defendant.	)	C.A. No. 07-49-JJF **DEMAND FOR JURY TRIAL**

AMENDED COMPLAINT

Plaintiffs FCI USA, Inc. ("FCI USA") and FCI Americas Technology, Inc. ("FCI Americas") (collectively, "FCI"), through their attorneys, complain of Defendant Molex Incorporated ("Defendant") and allege as follows, upon knowledge with respect to themselves and their own acts, and upon information and belief as to the circumstances and facts of others:

NATURE OF THE ACTION

1. This is an action for infringement of United States Patent Nos. 6,981,883 B2, 7,114,964 B2, and 7,182,643 B2 and arises under the patent laws of the United States, 35 U.S.C. § 1, *et seq.*

THE PARTIES

2. Plaintiff FCI USA, Inc. is a corporation organized under the laws of the State of New York, having a place of business at 825 Old Trail Road, Etters, Pennsylvania 17319-9769. Plaintiff FCI Americas Technology, Inc., a wholly-owned subsidiary of Plaintiff FCI USA, Inc.,

is a corporation organized under the laws of the State of Nevada, having a place of business at 825 Old Trail Road, Etters, Pennsylvania 17319-9769.

3. Upon information and belief, Defendant is a corporation organized under the laws of Delaware with a place of business at 2222 Wellington Court, Lisle, Illinois 60532. Defendant is registered to do business in the State of Delaware and has a registered agent, The Corporation Trust Company, located at 1209 Orange Street, Wilmington, Delaware 19801.

SUBJECT MATTER JURISDICTION

4. This Court has original jurisdiction over the subject matter of all causes of action herein pursuant to 28 U.S.C. §§ 1331 and 1338(a) because those causes of action arise under the patent laws of the United States, 35 U.S.C. § 1, *et seq.*

PERSONAL JURISDICTION

5. This Court has personal jurisdiction over Defendant because Defendant, on information and belief, is incorporated within the State of Delaware and resides therein.

VENUE

6. Venue in this judicial district is proper pursuant to 28 U.S.C. §§ 1391 and 1400(b) because, on information and belief, Defendant resides in this judicial district for purposes of jurisdiction.

FCI'S PATENT RIGHTS AND DEFENDANT'S VIOLATION THEREOF

7. On January 3, 2006, U.S. Patent No. 6,981,883 B2 (the "'883 patent") was duly and legally issued to Alan Raistrick and Joseph B. Shuey for an invention entitled "Impedance Control in Electrical Connectors." A true and correct copy of the '883 patent is attached to this Complaint as Exhibit A.

8. On October 3, 2006, U.S. Patent No. 7,114,964 B2 (the "'964 patent") was duly and legally issued to Clifford L. Winings, Joseph B. Shuey, Timothy A. Lemke, Gregory A. Hull, Stephen B. Smith, Stefaan Hendrik Josef Sercu, and Timothy W. Houtz for an invention entitled "Cross Talk Reduction and Impedance Matching For High Speed Connectors." A true and correct copy of the '964 patent is attached to this Complaint as Exhibit B.

9. On February 27, 2007, U.S. Patent No. 7,182,643 B2 (the "'643 patent") was duly and legally issued to Clifford L. Winings, Joseph B. Shuey, Timothy A. Lemke, Gregory A. Hull, Stephen B. Smith, Stefaan Hendrik Josef Sercu, Timothy W. Houtz, and Steven E. Minich for an invention entitled "Shieldless, High-Speed Electrical Connectors." A true and correct copy of the '643 patent is attached to this Complaint as Exhibit C.

10. FCI owns by assignment all right, title, and interest in and to the '883 patent, the '964 patent, and the '643 patent (collectively "FCI's patents").

11. Without authority or license from FCI, Defendant has acted and is acting to infringe FCI's patents by way of its activities involving high speed, shieldless electrical connectors, including those marketed under the I-TRAC name. On information and belief, these connectors have been and are being made, used, sold and/or offered for sale in the United States.

COUNT I

PATENT INFRINGEMENT – '883 PATENT

12. FCI repeats and realleges each and every allegation contained in paragraphs 1-11 of this Complaint as though fully set forth herein.

13. Defendant is infringing the '883 patent by making, using, importing, offering to sell, and/or selling high speed, shieldless electrical connectors, including those marketed under the I-TRAC name, in violation of 35 U.S.C. § 271(a).

14. Defendant's activities also have induced, are inducing, and/or will induce others to infringe the '883 patent in violation of 35 U.S.C. § 271(b).

15. Defendant is also liable for contributory infringement of the '883 patent in violation of 35 U.S.C. § 271(c).

16. Upon information and belief, the infringing acts of Defendant have been and are willful and deliberate, with knowledge of FCI's rights in and to the '883 patent.

17. As a direct and proximate consequence of Defendant's acts and practices, FCI has suffered, is suffering, and, unless such acts and practices are enjoined, will continue to suffer injury and damages for which it is entitled to relief under 35 U.S.C. § 284.

18. By reason of its acts and practices, Defendant has caused, is causing and, unless such acts and practices are enjoined, will continue to cause immediate and irreparable harm to FCI for which there is no adequate remedy at law, and for which FCI is entitled to injunctive relief under 35 U.S.C. § 283.

COUNT II

PATENT INFRINGEMENT – '964 PATENT

19. FCI repeats and realleges each and every allegation contained in paragraphs 1-18 of this Complaint as though fully set forth herein.

20. Defendant is infringing the '964 patent by making, using, importing, offering to sell, and/or selling high speed, shieldless electrical connectors, including those marketed under the I-TRAC name, in violation of 35 U.S.C. § 271(a).

21. Defendant's activities also have induced, are inducing, and/or will induce others to infringe the '964 patent in violation of 35 U.S.C. § 271(b).

22. Defendant is also liable for contributory infringement of the '964 patent in violation of 35 U.S.C. § 271(c).

23. Upon information and belief, the infringing acts of Defendant have been and are willful and deliberate, with knowledge of FCI's rights in and to the '964 patent.

24. As a direct and proximate consequence of Defendant's acts and practices, FCI has suffered, is suffering, and, unless such acts and practices are enjoined, will continue to suffer injury and damages for which it is entitled to relief under 35 U.S.C. § 284.

25. By reason of its acts and practices, Defendant has caused, is causing and, unless such acts and practices are enjoined, will continue to cause immediate and irreparable harm to FCI for which there is no adequate remedy at law, and for which FCI is entitled to injunctive relief under 35 U.S.C. § 283.

COUNT III

PATENT INFRINGEMENT – '643 PATENT

26. FCI repeats and realleges each and every allegation contained in paragraphs 1-25 of this Complaint as though fully set forth herein.

27. Defendant is infringing the '643 patent by making, using, importing, offering to sell, and/or selling high speed, shieldless electrical connectors, including those marketed under the I-TRAC name, in violation of 35 U.S.C. § 271(a).

28. Defendant's activities also have induced, are inducing, and/or will induce others to infringe the '643 patent in violation of 35 U.S.C. § 271(b).

29. Defendant is also liable for contributory infringement of the '643 patent in violation of 35 U.S.C. § 271(c).

30. Upon information and belief, the infringing acts of Defendant have been and are willful and deliberate, with knowledge of FCI's rights in and to the '643 patent.

31. As a direct and proximate consequence of Defendant's acts and practices, FCI has suffered, is suffering, and, unless such acts and practices are enjoined, will continue to suffer injury and damages for which it is entitled to relief under 35 U.S.C. § 284.

32. By reason of its acts and practices, Defendant has caused, is causing and, unless such acts and practices are enjoined, will continue to cause immediate and irreparable harm to FCI for which there is no adequate remedy at law, and for which FCI is entitled to injunctive relief under 35 U.S.C. § 283.

DEMAND FOR JURY TRIAL

33. FCI hereby requests a trial by jury for all issues so triable.

PRAYER FOR RELIEF

WHEREFORE, FCI prays that this Court enter judgment as follows, that:

A. Defendant be held liable under each claim for relief set forth in this Complaint;

B. Defendant has infringed and is infringing one or more claims of U.S. Patent Nos. 6,981,883 B2, 7,114,964 B2, and 7,182,643 B2;

C. Defendant's infringement of U.S. Patent Nos. 6,981,883 B2, 7,114,964 B2, and 7,182,643 B2 has been and is willful;

D. U.S. Patent Nos. 6,981,883 B2, 7,114,964 B2, and 7,182,643 B2 are valid and enforceable;

E. Defendant, its agents, servants, employees, and all other persons in active concert or participation with them be enjoined from further infringement of U.S. Patent Nos. 6,981,883 B2, 7,114,964 B2, and 7,182,643 B2;

F. Defendant be required to account for compensatory damages sustained by FCI and for punitive damages as a result of its patent infringement, together with interest, and that such damages will be increased to three times the amount found or assessed pursuant to 35 U.S.C. § 284;

G. Defendant be required to pay to FCI its reasonable attorneys' fees and disbursements incurred herein, pursuant to 35 U.S.C. § 285 and the equity powers of this Court;

L. Defendant be required to pay to FCI the costs of this action; and

M. This Court award FCI such other and further relief as this Court deems just and equitable.

MORRIS, NICHOLS, ARSHT & TUNNELL LLP

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February 27, 2007
752563

CERTIFICATE OF SERVICE

I hereby certify that on February 27, 2007, I caused to be served true and correct copies of the foregoing document on the following in the manner indicated below:

BY HAND

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752563

Exhibit A

US006981883B2

(12) **United States Patent**
Raistrick et al.

(10) **Patent No.: US 6,981,883 B2**
(45) **Date of Patent: Jan. 3, 2006**

(54) **IMPEDANCE CONTROL IN ELECTRICAL CONNECTORS**

(75) Inventors: **Alan Raistrick**, Rockville, MD (US); **Joseph B. Shuey**, Camp Hill, PA (US)

(73) Assignee: **FCI Americas Technology, Inc.**, Reno, NV (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/918,565**

(22) Filed: **Aug. 13, 2004**

(65) **Prior Publication Data**

US 2005/0020109 A1 Jan. 27, 2005

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/294,966, filed on Nov. 14, 2002, which is a continuation-in-part of application No. 09/990,794, filed on Nov. 14, 2001, now Pat. No. 6,692,272, and a continuation-in-part of application No. 10/155,786, filed on May 24, 2002, now Pat. No. 6,652,318.

(51) **Int. Cl.**
H01R 12/00 (2006.01)

(52) **U.S. Cl.** **439/74**

(58) **Field of Classification Search** 439/74, 439/75, 79, 701, 941, 608, 715
See application file for complete search history.

(56) **References Cited**

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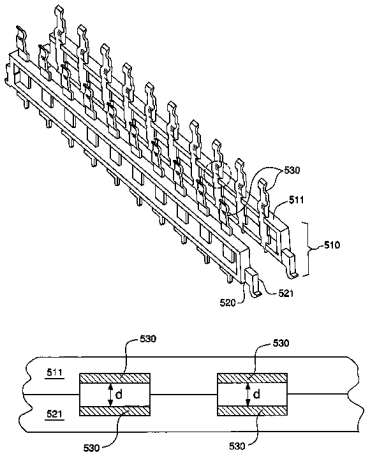
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Primary Examiner—Ross Gushi
(74) *Attorney, Agent, or Firm*—Woodcock Washburn LLP

(57) **ABSTRACT**

The invention provides a high speed connector wherein differential signal pairs are arranged so as to limit the level of cross talk between adjacent differential signal pairs. The connector comprises lead frame assembly having a pair of overmolded lead frame housings. Each lead frame housing has a respective signal contact extending therethrough. The lead frame housings may be operatively coupled such that the signal contacts form a broadside-coupled differential signal pair. The contacts may be separated by a gap having a gap width that enables insertion loss and cross talk between signal pairs to be limited.

31 Claims, 13 Drawing Sheets



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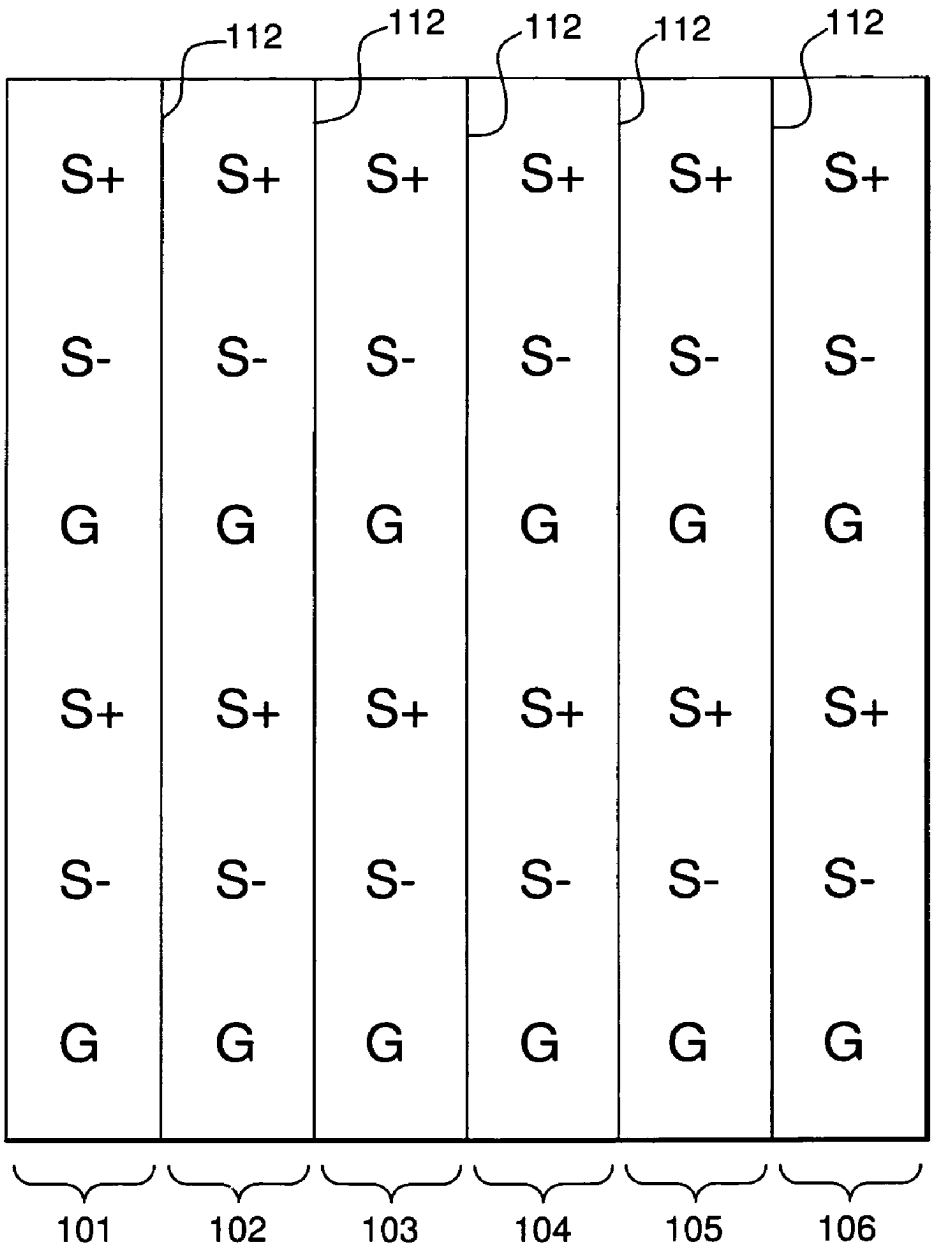


FIG. 1A
(PRIOR ART)

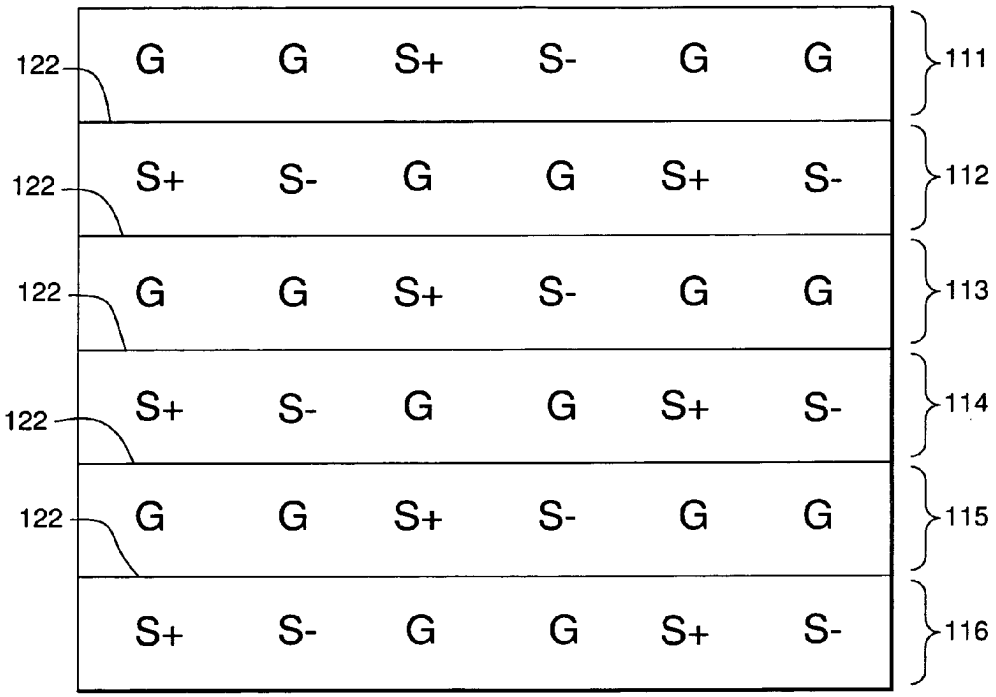


FIG. 1B
(PRIOR ART)

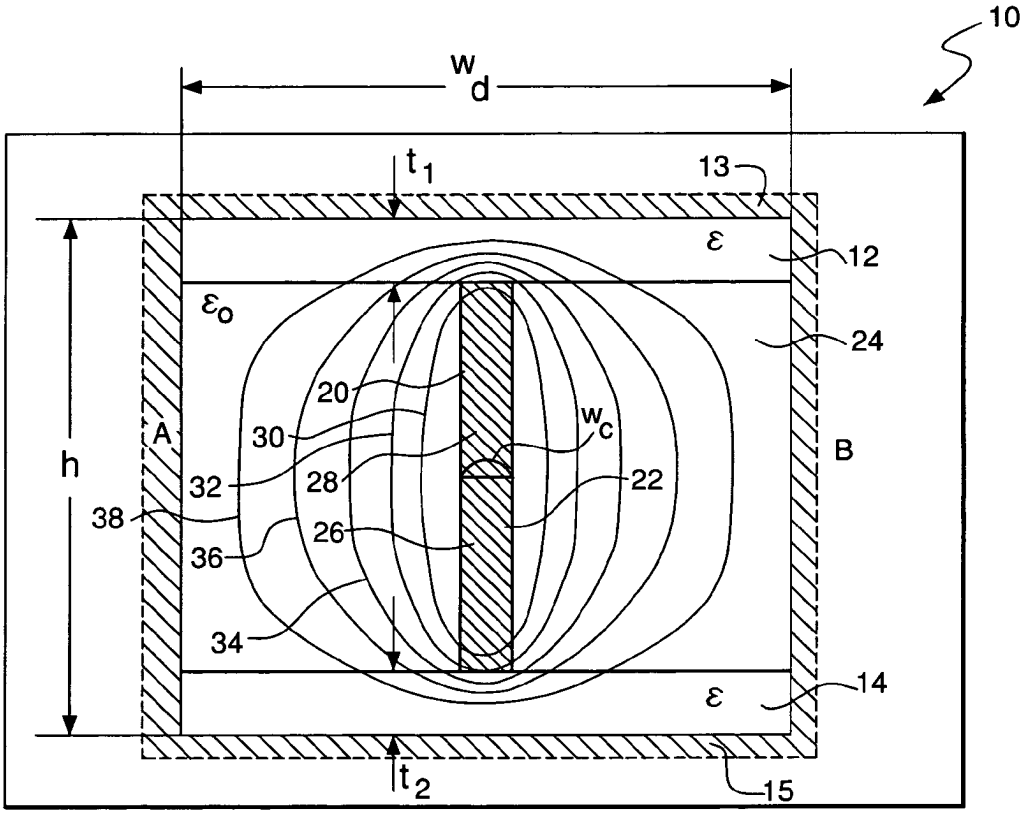


FIG. 2A
(PRIOR ART)

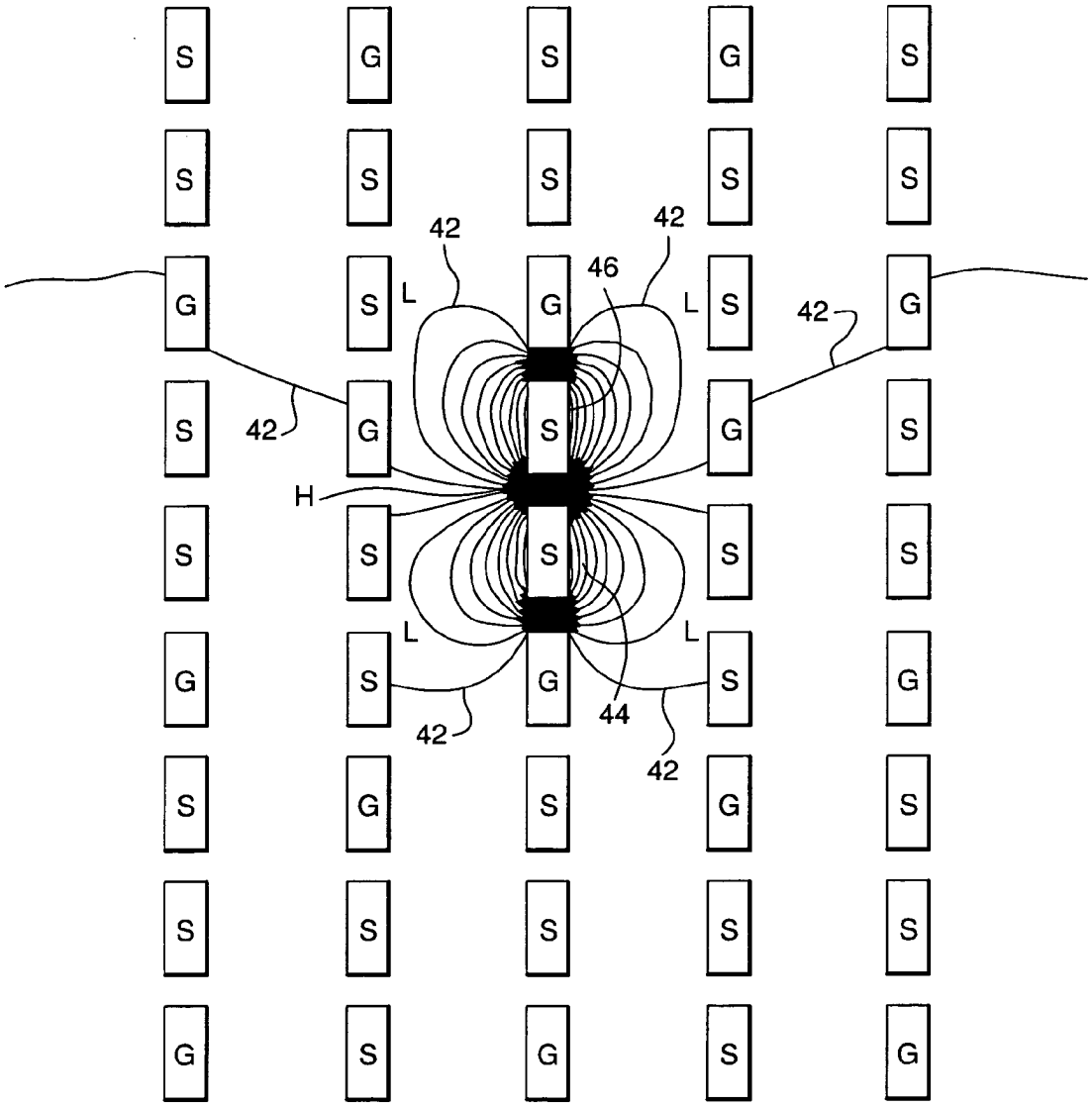


FIG. 2B

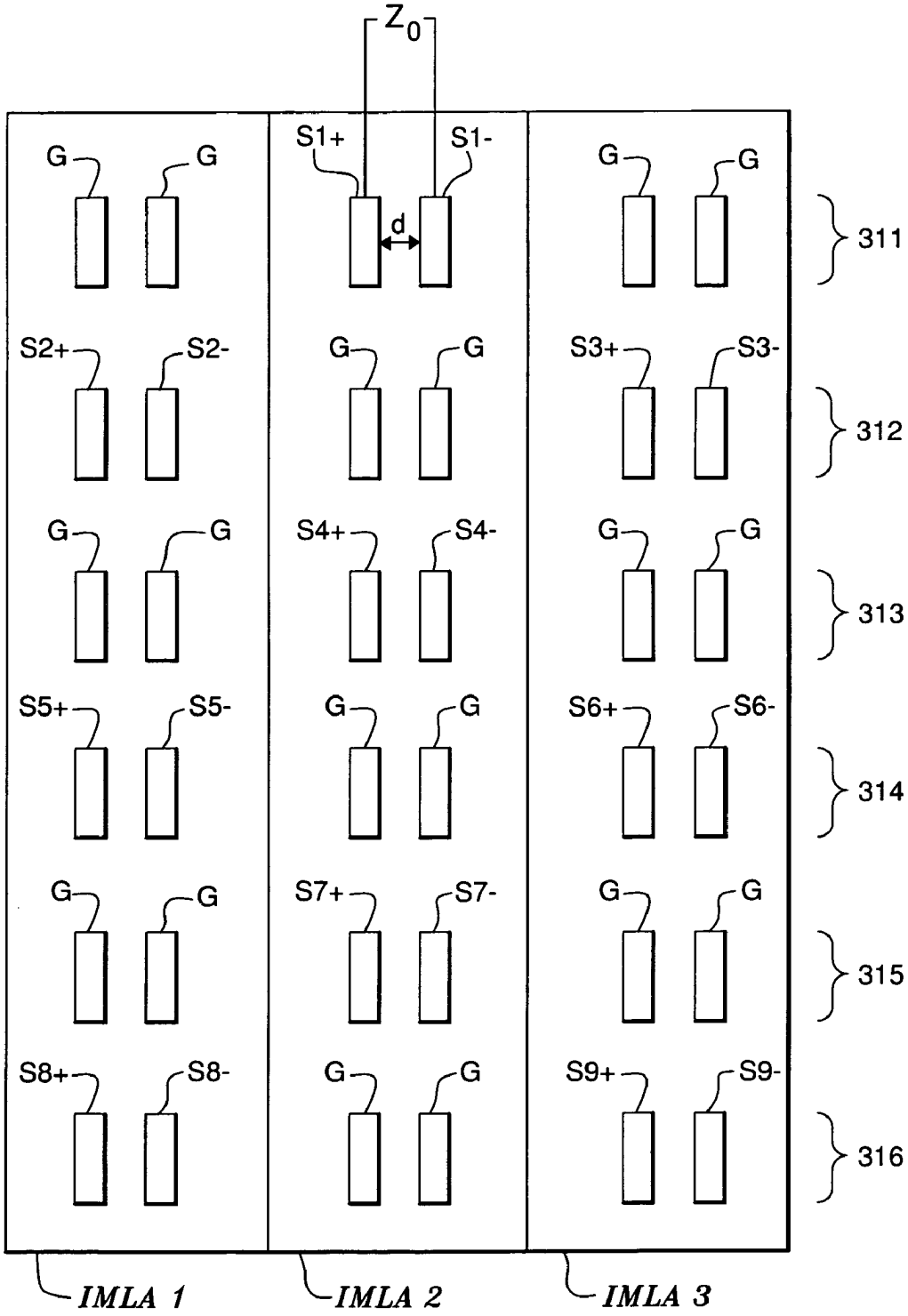

Z0
G
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S1-
d
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311
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S2-
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S3+
S3-
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S4+
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313
S5+
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S6+
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S7+
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316
IMLA 1
IMLA 2
IMLA 3

FIG. 3

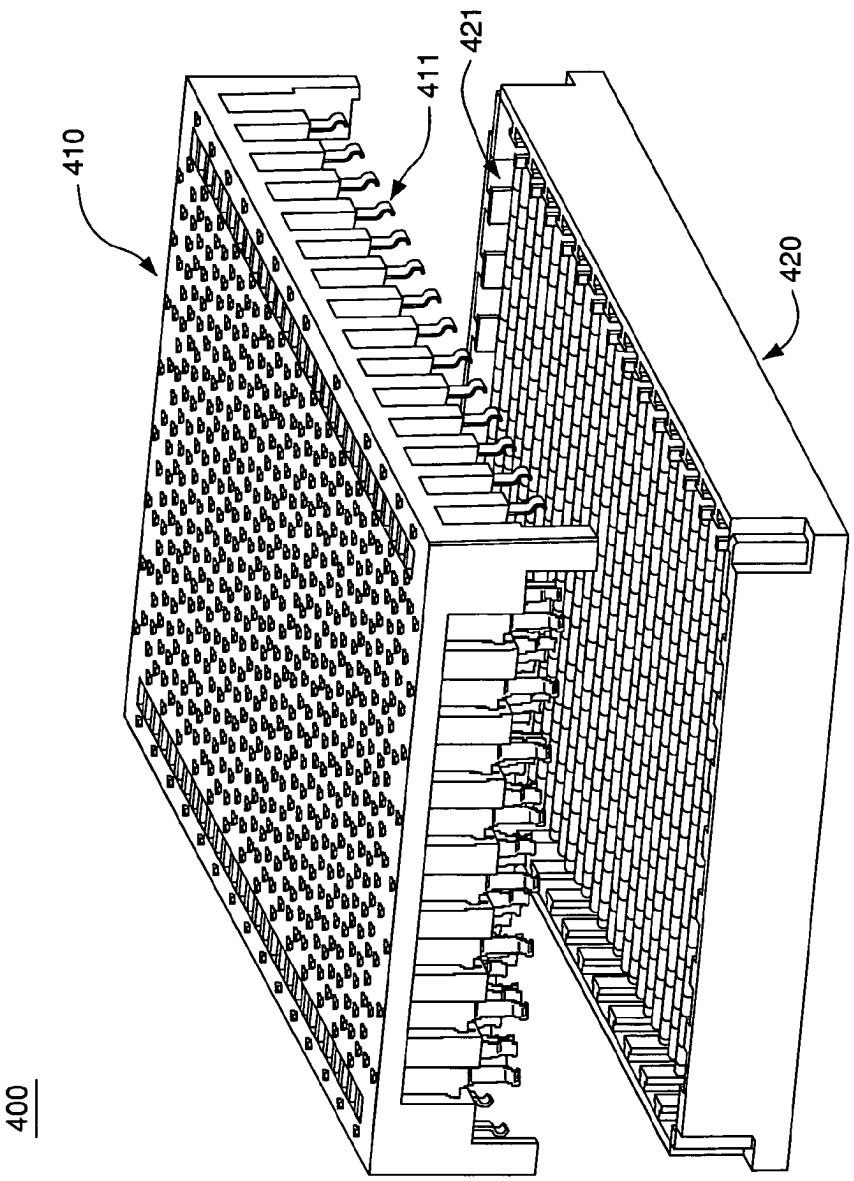


FIG. 4

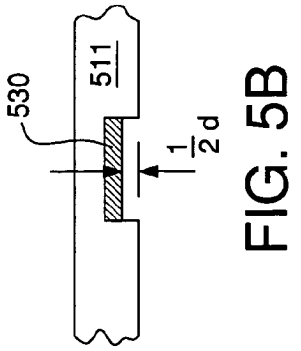


FIG. 5B

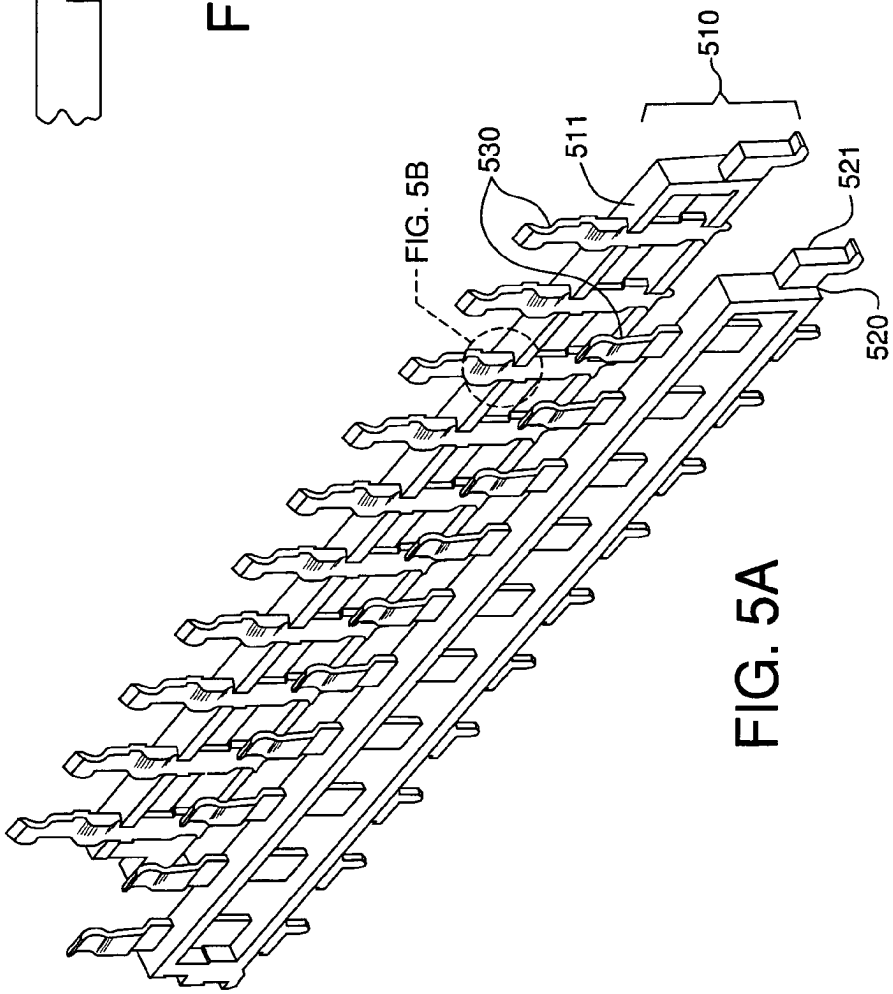


FIG. 5A

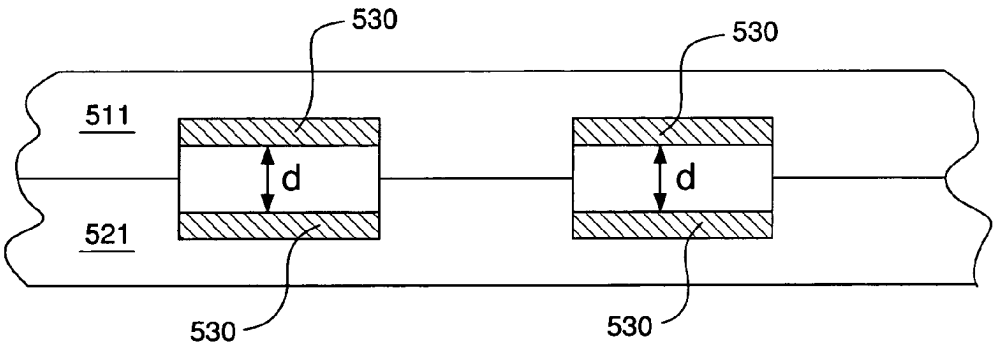


FIG. 5C

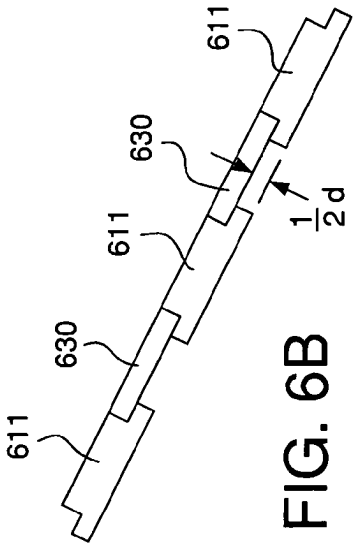


FIG. 6B

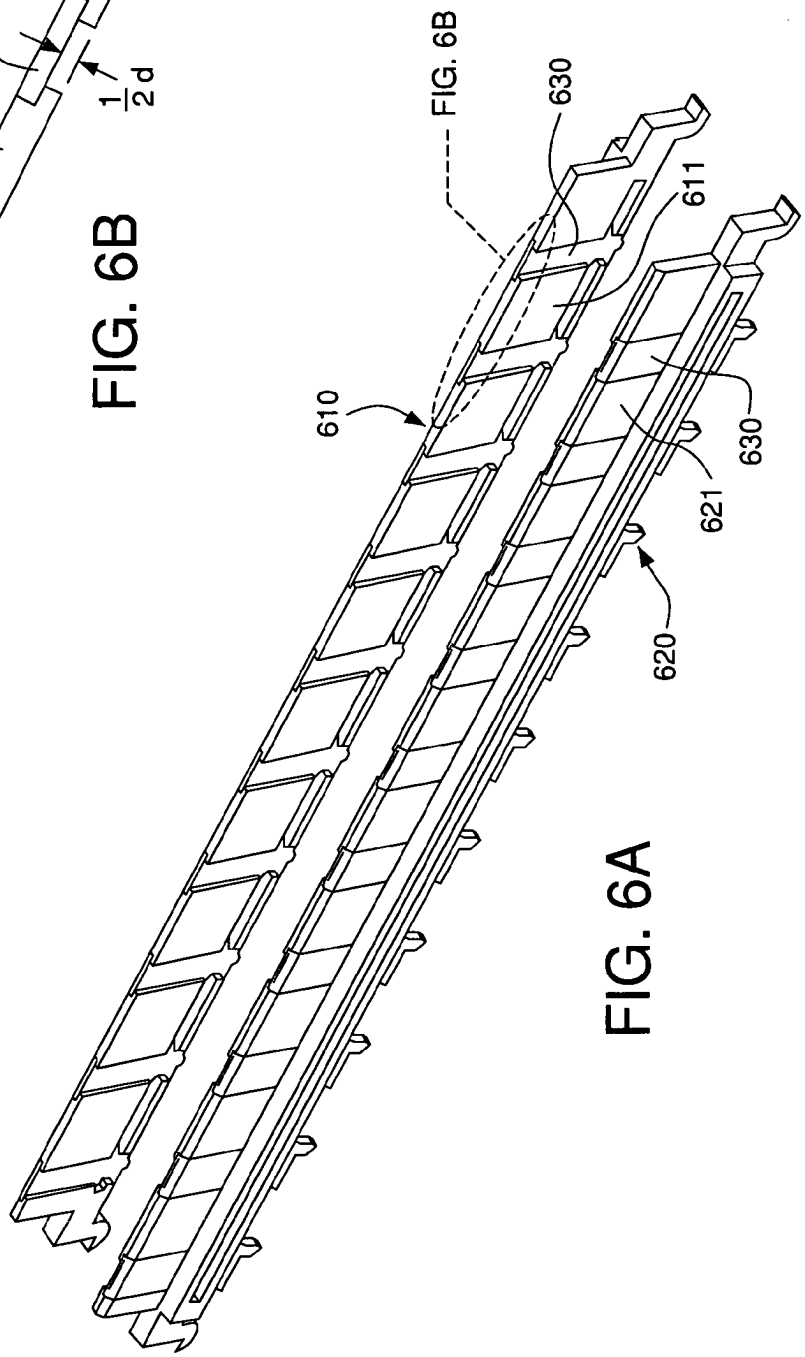


FIG. 6A

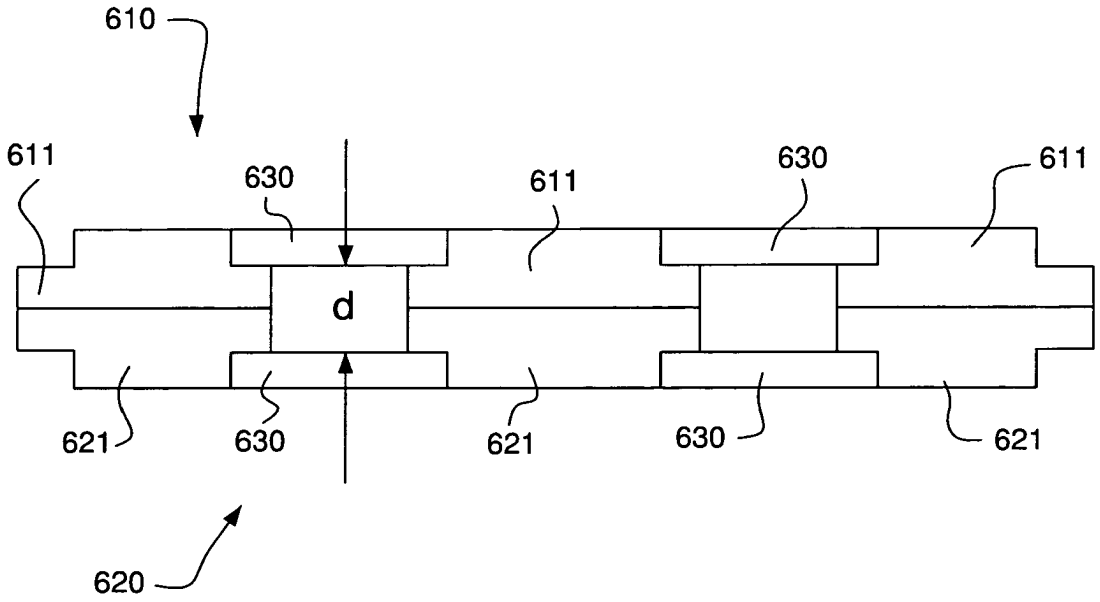


FIG. 6C

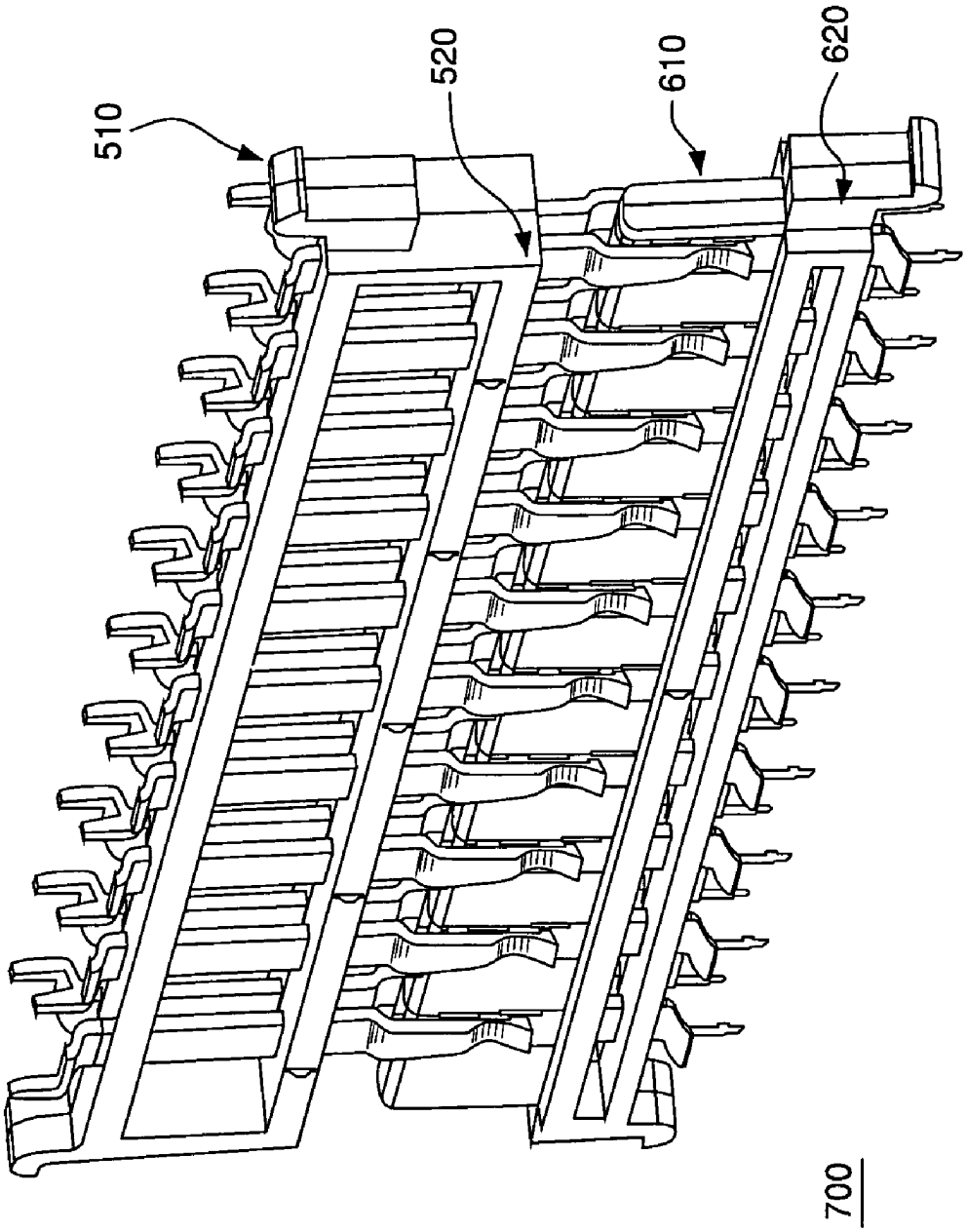


FIG. 7

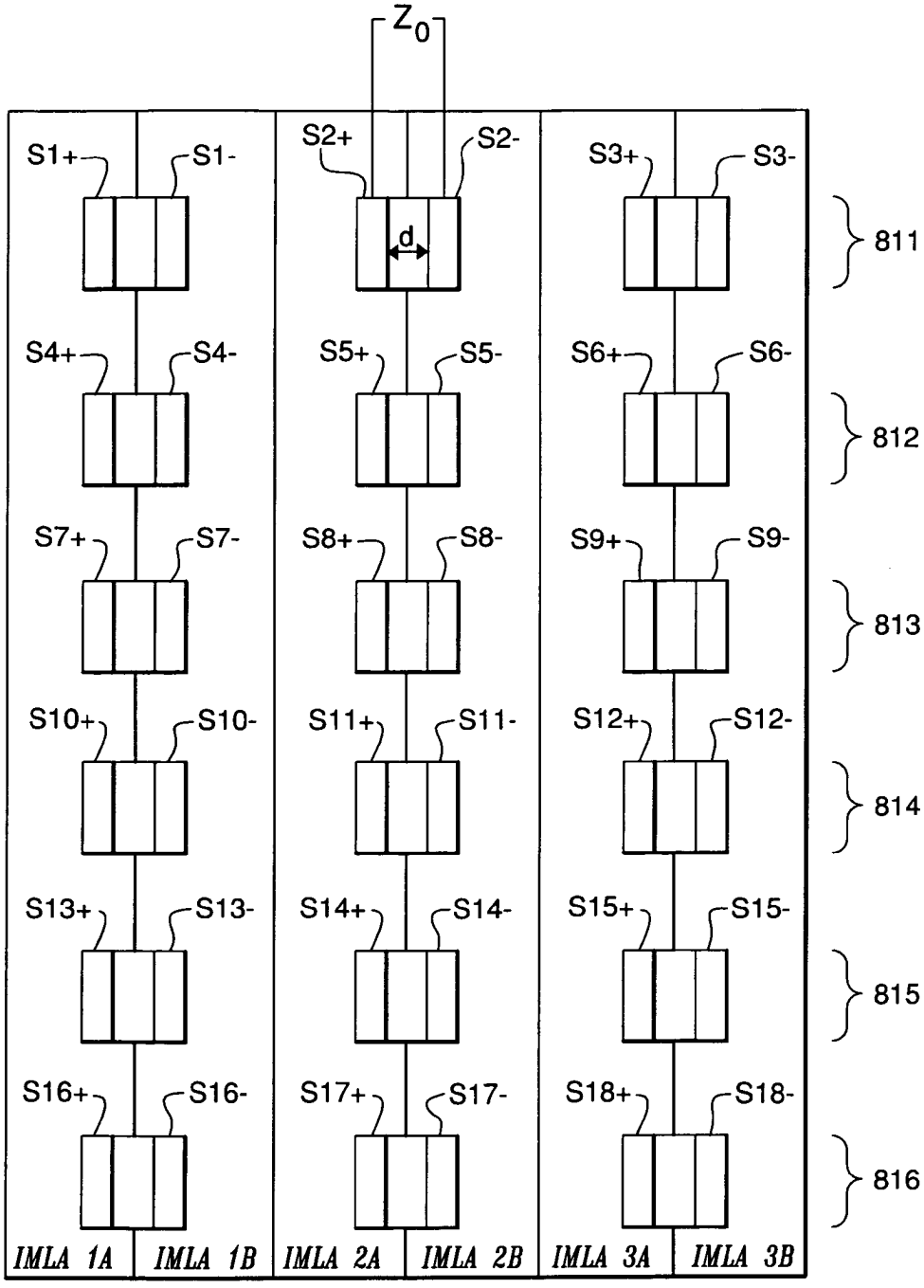

Z0
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S7+
S7-
S8+
S8-
S9+
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S12-
814
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S15+
S15-
815
S16+
S16-
S17+
S17-
S18+
S18-
816
IMLA 1A
IMLA 1B
IMLA 2A
IMLA 2B
IMLA 3A
IMLA 3B

FIG. 8A

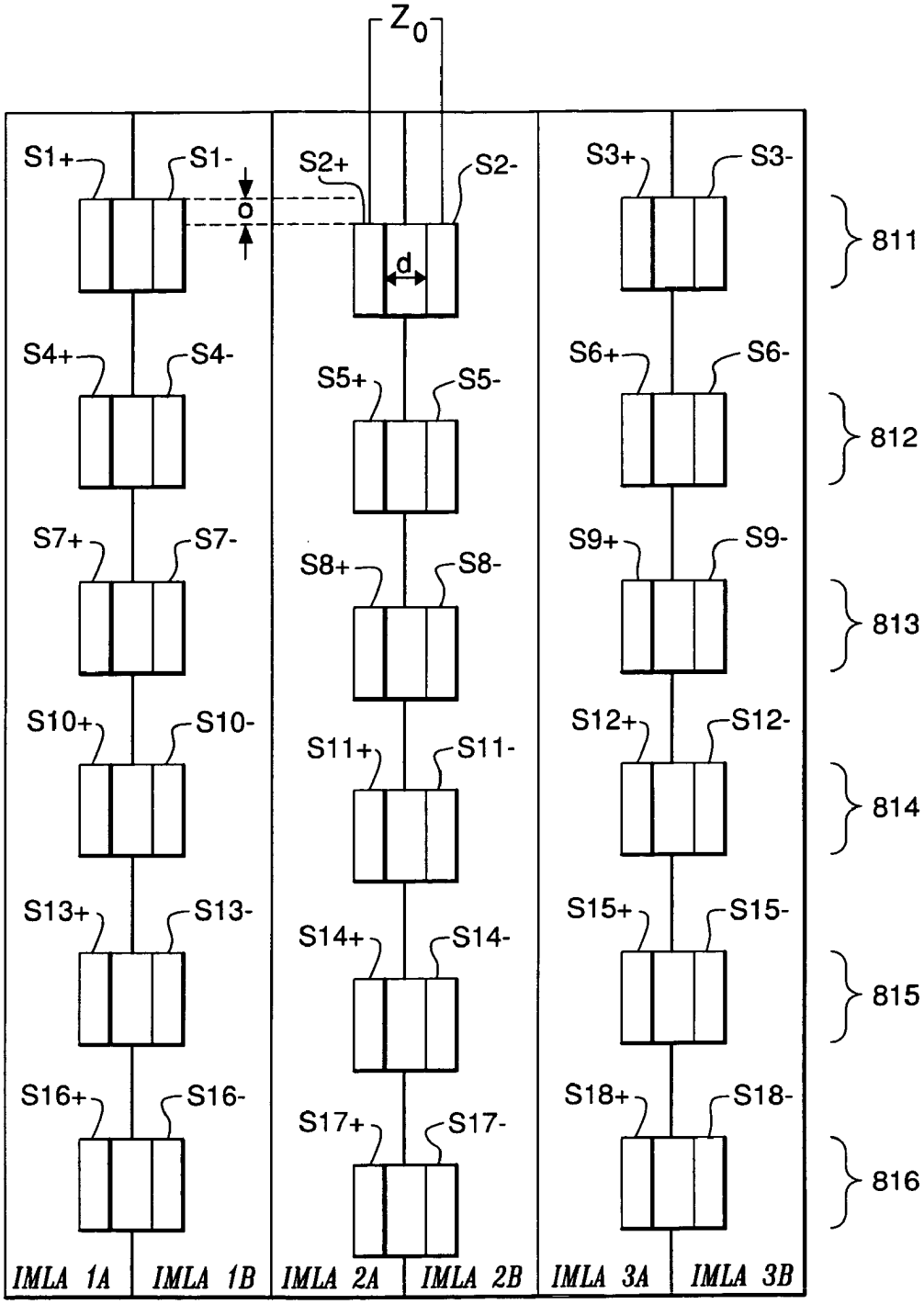

Z0
S1+
S1-
o
S2+
S2-
d
S3+
S3-
811
S4+
S4-
S5+
S5-
S6+
S6-
812
S7+
S7-
S8+
S8-
S9+
S9-
813
S10+
S10-
S11+
S11-
S12+
S12-
814
S13+
S13-
S14+
S14-
S15+
S15-
815
S16+
S16-
S17+
S17-
S18+
S18-
816
IMLA 1A
IMLA 1B
IMLA 2A
IMLA 2B
IMLA 3A
IMLA 3B

FIG. 8B

IMPEDANCE CONTROL IN ELECTRICAL CONNECTORS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of co-pending U.S. patent application Ser. No. 10/294,966, filed Nov. 14, 2002, which is a continuation-in-part of U.S. patent application Ser. No. 09/990,794, filed Nov. 14, 2001, now U.S. Pat. Nos. 6,692,272, and 10/155,786, filed May 24, 2002, now U.S. Pat. No. 6,652,318. The contents of each of the above-referenced U.S. patents and patent applications is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

Generally, the invention relates to the field of electrical connectors. More particularly, the invention relates to an impedance-controlled insert molded leadframe assembly ("IMLA") in a "split" configuration.

BACKGROUND OF THE INVENTION

Electrical connectors provide signal connections between electronic devices using signal contacts. Often, the signal contacts are so closely spaced that undesirable interference, or "cross talk," occurs between adjacent signal contacts. As used herein, the term "adjacent" refers to contacts (or rows or columns) that are next to one another. Cross talk occurs when one signal contact induces electrical interference in an adjacent signal contact due to intermingling electrical fields, thereby compromising signal integrity. With electronic device miniaturization and high speed, high signal integrity electronic communications becoming more prevalent, the reduction of cross talk becomes a significant factor in connector design.

One commonly used technique for reducing cross talk is to position separate electrical shields, in the form of metallic plates, for example, between adjacent signal contacts. Another commonly used technique to block cross talk between signal contacts is to place ground contacts amongst the signal contacts of a connector. The shields and ground contacts act to block cross talk between the signal contacts by blocking the intermingling of the contacts' electric fields. FIGS. **1**A and **1**B depict exemplary contact arrangements for electrical connectors that use shields to block cross talk.

FIG. **1**A depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along columns **101**–**106**. As can be seen in FIG. **1**A, the signal pairs are edge coupled (i.e., where the edge of one contact is adjacent to the edge of an adjacent contact). Shields **112** can be positioned between contact columns **101**–**106**. A column **101**–**106** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same column. The shields **112** serve to block cross talk between differential signal pairs in adjacent columns.

FIG. **1**B depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along rows **111**–**116**. As can be seen in FIG. **1**B, the signal pairs are broadside-coupled (i.e., where the broad side of one contact is adjacent to the broad side of an adjacent contact). Shields **122** can be positioned between rows **111**–**116**. A row **111**–**116** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same row. The shields **122** serve to block cross talk between differential signal pairs in adjacent rows.

Because of the demand for smaller, lower weight communications equipment, it is desirable that connectors be made smaller and lower in weight, while providing the same performance characteristics. Shields and ground contacts take up valuable space within the connector that could otherwise be used to provide additional signal contacts, and thus limit contact density (and, therefore, connector size). Additionally, manufacturing and inserting such shields and ground contacts substantially increase the overall costs associated with manufacturing such connectors. For example, in some applications, shields are known to make up 40% or more of the cost of the connector. Another known disadvantage of shields is that they lower impedance. Thus, to make the impedance high enough in a high contact density connector, the contacts would need to be so small that they would not be robust enough for many applications. Furthermore, ground contacts can take up a large percentage of the available contacts in a connector, thus causing an increase in size and weight of the connector for a given number of differential signal pairs.

Therefore, a need exists for a lightweight, high-speed electrical connector that reduces the occurrence of cross talk without the need for separate shields or ground contacts, and provides for a variety of other benefits not found in prior art connectors. More particularly, what is needed is an impedance-controlled insert molded leadframe assembly (IMLA) that maintains a distance between broadside coupled signal pairs such that cross-talk between signal pairs may be limited without the use of shields or ground contacts.

SUMMARY OF THE INVENTION

The invention provides a high speed connector wherein differential signal pairs are arranged so as to limit the level of cross talk between adjacent differential signal pairs. The connector comprises a plurality of signal contact pairs, where the contacts of each pair are separated by a gap. The gap is formed over a distance such that insertion loss and cross talk between the plurality of signal contact pairs are limited. Thus, shields and/or ground contacts are not needed in an embodiment.

In one embodiment, the connector may be comprised of a header leadframe assembly and a receptacle leadframe assembly. Each leadframe assembly may include an overmolded housing and a set of contacts that extend through the housing. Each leadframe assembly may be adapted to maintain the width of the gap between contacts that form a pair along respective portions of the contacts that extend through the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further described in the detailed description that follows, by reference to the noted drawings by way of non-limiting illustrative embodiments of the invention, in which like reference numerals represent similar parts throughout the drawings, and wherein:

FIGS. **1**A and **1**B depict exemplary prior art contact arrangements for electrical connectors that use shields to block cross talk;

FIG. **2**A is a schematic illustration of a prior art electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry;

FIG. **2**B depicts equipotential regions within an arrangement of signal and ground contacts;

FIG. **3** depicts a conductor arrangement in which signal pairs are arranged in rows;

FIG. **4** depicts a mezzanine-style connector assembly in accordance with an example embodiment of the invention;

FIGS. **5**A–C depict a receptacle IMLA pair in accordance with an embodiment of the present invention;

FIGS. **6**A–C depict a header IMLA pair in accordance with an embodiment of the present invention;

FIG. **7** depicts a header and receptacle IMLA pair in operative communications in accordance with an embodiment of the present invention; and

FIGS. **8**A–B depict exemplary contact arrangements for an electrical connector in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The subject matter of the present invention is described with specificity to meet statutory requirements. However, the description itself is not intended to limit the scope of this patent. Rather, the inventors have contemplated that the claimed subject matter might also be embodied in other ways, to include different steps or elements similar to the ones described in this document, in conjunction with other present or future technologies. Moreover, certain terminology may be used in the following description for convenience only and should not be considered as limiting the invention in any way. For example, the terms "top," "bottom," "left," "right," "upper," and "lower" designate directions in the figures to which reference is made. Likewise, the terms "inwardly" and "outwardly" designate directions toward and away from, respectively, the geometric center of the referenced object. The terminology includes the words above specifically mentioned, derivatives thereof, and words of similar import.

FIG. **2**A is a schematic illustration of an electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry. Such connectors are embodied in the assignee's "I-BEAM" technology, and are described and claimed in U.S. Pat. No. 5,741,144, entitled "Low Cross And Impedance Controlled Electric Connector," the disclosure of which is hereby incorporated herein by reference in its entirety. Low cross talk and controlled impedance have been found to result from the use of this geometry.

The originally contemplated I-shaped transmission line geometry is shown in FIG. **2**A. As shown, the conductive element can be perpendicularly interposed between two parallel dielectric and ground plane elements. The description of this transmission line geometry as I-shaped comes from the vertical arrangement of the signal contact shown generally at numeral **10** between the two horizontal dielectric layers **12** and **14** having a dielectric constant ϵ and ground planes **13** and **15** symmetrically placed at the top and bottom edges of the conductor. The sides **20** and **22** of the conductor are open to the air **24** having an air dielectric constant ϵ_0. In a connector application, the conductor could include two sections, **26** and **28**, that abut end-to-end or face-to-face. The thickness, t_1 and t_2 of the dielectric layers **12** and **14**, to first order, controls the characteristic impedance of the transmission line and the ratio of the overall height h to dielectric width w_d controls the electric and magnetic field penetration to an adjacent contact. Original experimentation led to the conclusion that the ratio h/w_d needed to minimize interference beyond A and B would be approximately unity (as illustrated in FIG. **2**A).

The lines **30**, **32**, **34**, **36** and **38** in FIG. **2**A are equipotentials of voltage in the air-dielectric space. Taking an equipotential line close to one of the ground planes and following it out towards the boundaries A and B, it will be seen that both boundary A or boundary B are very close to the ground potential. This means that virtual ground surfaces exist at each of boundary A and boundary B. Therefore, if two or more I-shaped modules are placed side-by-side, a virtual ground surface exists between the modules and there will be little to no intermingling of the modules' fields. In general, the conductor width w_c and dielectric thicknesses t_1, t_2 should be small compared to the dielectric width W_d or module pitch (i.e., distance between adjacent modules).

Given the mechanical constraints on a practical connector design, it was found in actuality that the proportioning of the signal contact (blade/beam contact) width and dielectric thicknesses could deviate somewhat from the preferred ratios and some minimal interference might exist between adjacent signal contacts. However, designs using the above-described I-shaped geometry tend to have lower cross talk than other conventional designs.

In accordance with an embodiment of the invention, the basic principles described above were further analyzed and expanded upon and can be employed to determine how to even further limit cross talk between adjacent signal contacts. Such analysis first addresses the need to remove shields from between the contacts by determining an appropriate arrangement and geometry of the signal and ground contacts. FIG. **2**B includes a contour plot of voltage in the neighborhood of an active column-based differential signal pair S+, S− in a contact arrangement of signal contacts S and ground contacts G according to the invention. As shown, contour lines **42** are closest to zero volts, contour lines **44** are closest to −1 volt, and contour lines **46** are closest to +1 volt. It has been observed that, although the voltage does not necessarily go to zero at the "quiet" differential signal pairs that are nearest to the active pair, the interference with the quiet pairs is near zero. That is, the voltage impinging on the positive-going quiet differential pair signal contact is about the same as the voltage impinging on the negative-going quiet differential pair signal contact. Consequently, the noise on the quiet pair, which is the difference in voltage between the positive- and negative-going signals, is close to zero.

Thus, as shown in FIG. **2**B, the signal contacts S and ground contacts G can be scaled and positioned relative to one another such that a differential signal in a first differential signal pair produces a high field H in the gap between the contacts that form the signal pair and a low (i.e., close to ground potential) field L (close to ground potential) near an adjacent signal pair. Consequently, cross talk between adjacent signal contacts can be limited to acceptable levels for the particular application. In such connectors, the level of cross talk between adjacent signal contacts can be limited to the point that the need for (and cost of) shields between adjacent contacts is unnecessary, even in high speed, high signal integrity applications.

Through further analysis of the above-described I-shaped model, it has been found that the unity ratio of height to width is not as critical as it first seemed. It has also been found that a number of factors can affect the level of cross talk between adjacent signal contacts. For example, it has been found that one such factor is the distance between the broadside-coupled contacts that form a differential signal pair. In an embodiment, therefore, the careful control of the distance between the broadside-coupled contacts may be

used to maintain an appropriate differential impedance Z_0 so as to reduce cross talk between signal pairs. Such a configuration is particularly suitable for mezzanine-style connectors, and such a connector will be discussed below in connection with FIGS. **5**A–**8**. However, it will be appreciated that the invention is not limited to mezzanine connectors, and may be employed in a variety of connector applications.

FIG. **3** depicts a conductor arrangement in which signal pairs and ground contacts are arranged in rows. The conductor arrangement of FIG. **3** is shown for purposes of comparison, as the arrangement does not depict the "split IMLA" configuration to be discussed below in connection with FIGS. **4**–**8**B. As shown in FIG. **3**, each row **311**–**316** comprises a repeating sequence of two ground contacts and a differential signal pair. Row **311**, for example, comprises, in order from left to right, two ground contacts G, a differential signal pair **S1+**, **S1–**, and two ground contacts G. Row **312**, for example, comprises, in order from left to right, a differential signal pair **S2+**, **S2–**, two ground contacts G, and a differential signal pair **S3+**, **S3–**. In the embodiment shown in FIG. **3**, it can be seen that the columns of contacts can be arranged as insert molded leadframe assemblies ("IMLAs"), such as IMLAs **1**–**3**. The ground contacts may serve to block cross talk between adjacent signal pairs. However, the ground contacts take up valuable space within the connector. As can be seen, the embodiment shown in FIG. **3** is limited to only nine differential signal pairs for an arrangement of 36 contacts because of the presence of the ground contacts.

Regardless of whether the signal pairs are arranged into rows (broadside-coupled) or columns (edge coupled), each differential signal pair has a differential impedance Z_0 between the positive and negative conductors of the differential signal pair. Differential impedance is defined as the impedance existing between two signal contacts of the same differential signal pair, at a particular point along the length of the differential signal pair. As is well known, it is desirable to control the differential impedance Z_0 to match the impedance of the electrical device(s) to which the connector is connected. Matching the differential impedance Z_0 to the impedance of an electrical device minimizes signal reflection and/or system resonance that can limit overall system bandwidth. Furthermore, it is desirable to control the differential impedance Z_0 such that it is substantially constant along the length of the differential signal pair, i.e., such that each differential signal pair has a substantially consistent differential impedance profile. The distance d of an air dielectric between the contacts that form a differential signal pair (such as signal contacts **S1+** and **S1–**, for example) can determine the impedance Z_0 between each of the contacts.

As noted above, the differential impedance profile can be controlled by the positioning of the signal and ground contacts. Specifically, differential impedance Z_0 can be determined by the proximity of an edge of a signal contact to an adjacent ground and by the gap distance d between edges of signal contacts within a differential signal pair. However, and significantly, if a proper geometry of broadside-coupled differential signal pairs is attained by precisely maintaining the distance between the contacts of the signal pair, the cross talk between multiple differential signal pairs can be reduced to the point that ground contacts are unnecessary. In other words, the signal quality that results from precisely maintaining an appropriate distance between broadside-coupled signal pairs is high enough to render any additional improvement in signal quality that may be gained by the presence of ground contacts either irrelevant for the connector's intended application, or not worth the attendant increase in size and/or weight of the connector.

To maintain acceptable differential impedance Z_0 control for high bandwidth systems, it is desirable to control the gap distance d between contacts to within a few thousandths of an inch. Gap variations beyond a few thousandths of an inch may cause unacceptable variation in the impedance profile; however, the acceptable variation is dependent on the speed desired, the error rate acceptable, and other design factors, any weighing or consideration of which is equally consistent with an embodiment of the present invention. When both contacts of a given signal pair are formed within the same IMLA, the distance d is difficulty to maintain at the levels of precision desired for establishing and maintaining a near-constant differential impedance Z_0.

According to an embodiment of the invention, a "split" IMLA configuration is provided where each IMLA has two lengthwise housing halves, each half corresponding to a respective contact column. It will be appreciated in the discussion that follows that the placing of one contact of a signal pair in a recess of each portion of the lead frame assembly (e.g., the header or receptacle portions of the IMLA) enables greater precision in maintaining the gap distance d between contacts. As a result, the differential impedance Z_0 can be controlled so as to minimize cross-talk between signal pairs to such an extent as necessary to enable removal of the ground contacts.

Referring now to FIG. **4**, a mezzanine-style connector assembly in accordance with one embodiment of the invention is depicted. It will be appreciated that a mezzanine connector is a high-density stacking connector used for parallel connection of printed circuit boards and the like. Such a mezzanine connector can be used to relocate, for example, high pin count devices onto mezzanine or module cards to simplify board routing without compromising system performance. The mezzanine connector assembly **400** illustrated in FIG. **4** comprises a receptacle **410** having receptacle grounds **411** arranged around the outside of the receptacle **410**, and a header **420** having header grounds **421** arranged around the outside of the header **420**. The header **420** also contains header IMLAs (not individually labeled in FIG. **4** for clarity) and the receptacle **410** contains receptacle IMLAs (also not individually labeled in FIG. **4** for clarity). It will be appreciated that the receptacle **410** and header **420** can be mated to operatively connect the receptacle and header IMLAs. It will also be appreciated that, according to one embodiment of the invention, the grounds shown in FIG. **4**, may be the only grounds in the connector.

As noted above, maintaining careful control of the distance between broadside-coupled contacts that form signal pairs can reduce cross talk between signal pairs. In an embodiment of the invention, such distance control is maintained by using each "split" half of an IMLA (e.g., receptacle and header IMLAs) to maintain precise spacing between contacts of a differential signal pair throughout a connector.

FIGS. **5**A–C depict a receptacle IMLA pair in accordance with an embodiment of the invention. Referring first to FIG. **5**A, a first receptacle IMLA **510** comprises an overmolded housing **511** and a series of receptacle contacts **530**, and a second receptacle IMLA **520** comprises an overmolded housing **521** and a series of receptacle contacts **530**. As can be seen in FIG. **5**A, the receptacle contacts **530** are recessed into the housings of receptacle IMLAs **510** and B **520**. It will be appreciated that fabrication techniques permit the recesses in each portion of the IMLA **510**, **520** to be sized very precisely. As a result, the gap distance d between each

signal contact can be maintained throughout a connector fabricated in accordance with an embodiment of the present invention.

Turning now to FIG. **5**B, a detailed view of one such recessed receptacle contact **530** in receptacle IMLA **510** is shown. As can be seen in FIG. **5**B, the housing **511** of receptacle IMLA **510** is recessed so the contact **530** sits within the housing such that the distance from the outside broad side of the contact **530** to the outside edge of the housing **511** is ½d. The total distance d extends from the outside broad side of the contact **530** to the outside broad side of a contact **530** of receptacle IMLA **520** (not shown in FIG. **5**B for clarity), with which IMLA **510** will be operatively coupled. It will readily be appreciated that the distance provided by either IMLA **510** or IMLA **520** can be any fraction of d, so long as the total distance d is formed when IMLA **510** and IMLA **520** are operatively coupled.

FIG. **5**C shows a detailed view of receptacle IMLA **510** operatively coupled to receptacle IMLA **520**. It will be appreciated that in an embodiment any manner of operatively coupling receptacle IMLAs **510** and B **520** may be used. Thus, in an interference fit, fasteners and the like may be used alone or in any combination to affect such coupling.

In FIG. **5**C, it can be seen that the housing **511** of receptacle IMLA **510** abuts the housing **521** of receptacle IMLA **520**. Contacts **530** sit within respective recesses in the housings **511** and **521**. It will be appreciated that operatively coupling the overmolded housings **511** and **521** as shown in FIG. **5**C places a broad side of each contact **530** (i.e., the broad side that is facing the opposing contact **530**) at a distance d from the opposing contact **530**. In an embodiment, the distance d is able to be maintained at a high level of precision because of the low tolerances possible with overmolded housing fabrication, as well as contact fabrication. Because the distance d only depends on these two, highly-precise components, the distance d can be maintained within the very low acceptable variations that are needed to maintain an appropriate differential impedance Z_0.

It will be appreciated that, in an embodiment of the invention, the distance d may be bridged by an air dielectric as discussed above. Thus, the weight of the resulting connector, of which the receptacle IMLAs **510** and **520** are a part, may be minimized. It will also be appreciated that the ability to closely control the size of the recess within each overmolded housing **511**, **521** enables the impedance Z_0 between the contacts that form signal pairs (and, consequently, cross-talk between signal pairs) to be closely controlled.

Because the above-mentioned differential impedance Z_0 (and therefore cross talk between signal pairs) is controlled by maintaining a precise distance d, it will be appreciated that a header ILMLA that is to be coupled to a receptacle IMLA should also carefully maintain a precise distance d between signal pairs. Therefore, and turning now to FIGS. **6**A–C, a header IMLA pair in accordance with an embodiment of the present invention is depicted. Referring first to FIG. **6**A, header IMLA **610** comprises an overmolded housing **611** and a series of header contacts **630**, and header IMLA **620** comprises an overmolded housing **621** and a series of header contacts **630**. As can be seen in FIG. **6**A, the header contacts **630** are recessed into the housings of header IMLAs **610** and **620**.

Turning now to FIG. **6**B, a detailed view of one such recessed header contact **630** in header IMLA **610** is shown. As can be seen in FIG. **6**B, the housing **611** of IMLA **610** is recessed so the contact **630** sits within the housing such that the distance from the inside broad side of the contact **630** to the inside edge of the housing **611** (i.e., the side of the housing **611** that will abut the housing **621** of header IMLA **620**—not shown in FIG. **6**B for clarity) is ½ the total distance d from the inside broad side of the contact **630** to the inside broad side of a contact **630** of IMLA **620**. Again, it will readily be appreciated that the distance provided by either IMLA **610** or IMLA **620** can be any fraction of d, so long as the distance d is formed when IMLA **610** and IMLA **620** are operatively coupled.

FIG. **6**C shows a detailed view of header IMLA **610** operatively coupled to header IMLA **620**. It will be appreciated that in an embodiment any manner of operatively coupling header IMLAs **610** and **620** may be used. Thus, an interference fit, fasteners and the like may be used alone or in any combination to affect such coupling, and any such coupling may be accomplished by the same or a different method used to operatively couple the receptacle IMLAs discussed above in connection with FIGS. **5**A–C.

In FIG. **6**C, it can be seen that the housing **611** of header IMLA **610** abuts the housing **621** of header IMLA **620**. Within respective recesses in both housings **611** and **621** are contacts **630**. It will be appreciated that operatively coupling the housings **611** and **621** as shown in FIG. **6**C places a respective broad side of each contact **630** (i.e., the broad side that is facing the opposing contact **630**) at a distance d from the opposing contact **630**. Thus, the differential impedance Z_0 as discussed above in connection with FIG. **3** may be established because of the distance d maintained between the contacts **630** of header IMLAs **610** and **620**. It will also be appreciated that the aforementioned ability to closely control the size of the recess within each housing **611**, **621**, as well as the contact size, enables differential impedance Z_0 and cross-talk to be closely controlled.

Turning now to FIG. **7**, a header and receptacle IMLA pair in operative communications in accordance with an embodiment of the present invention is depicted. In FIG. **7**, it can be seen that header IMLAs **610** and B **620** are operatively coupled to form a single and complete header IMLA. Likewise, receptacle IMLAs **510** and B **520** are operatively coupled to form a single and complete receptacle IMLA. While FIG. **7** illustrates an interference fit between the contacts **630** of the receptacle IMLA and the contacts of the header IMLA, it will be appreciated that any method of causing electrical contact, and/or for operatively coupling the header IMLA to the receptacle IMLA, is equally consistent with an embodiment of the present invention.

As can be seen in FIG. **7**, the contacts of the receptacle IMLA may be flared to accept the contacts of the header IMLA. As a result, the precise maintenance of the distance d between contacts within both the receptacle IMLA and the header IMLA enables the differential impedance Z_0 to be carefully controlled through the connector. This, in turn, minimizes cross talk between signal pairs, even in the absence of ground contacts.

Turning now to FIG. **8**A, a conductor arrangement is depicted in which signal pairs are arranged in rows. As can be seen in FIG. **8**A, each row **811**–**816** comprises a plurality of differential signal pairs. First row **811** comprises, in order from left to right, three differential signal pairs: **S1+** and **S1–**, **S2+** and **S2–**, and **S3+** and **S3–**. Each additional row in the exemplary arrangement of FIG. **8**A contains three differential signal pairs. In the embodiment shown in FIG. **8**A, and as was the case with FIG. **3**, it can be seen that the columns of contacts can be arranged as IMLAs, such as IMLAs **1**–**3**. In addition, each IMLA has two lengthwise halves in a split configuration, A and B, that correspond to each column. Unlike the arrangement discussed above in

connection with FIG. **3**, no ground contacts are needed because the cross talk between adjacent signal pairs may be minimized by the proper selection of the differential impedance Z_0 that is possible by maintaining a precise distance d between signal contacts. Thus, in an embodiment of the invention, and as shown in FIG. **8**A, the connector may be devoid of ground contacts.

As can be seen, therefore, the embodiment shown in FIG. **8**A provides 18 differential signal pairs for an arrangement of 36 contacts, which is a significant improvement over the nine differential signal pairs in the arrangement depicted above in FIG. **3**. Thus, a connector according to the invention may be lighter and smaller for a given number of differential signal pairs, or have a greater concentration of differential signal pairs for a given weight and/or size of the connectors.

It will be appreciated that an embodiment of the present invention encompasses any number of conductor arrangements. For example, the conductor arrangement depicted in FIG. **8**B shows that adjacent columns of broadside-coupled pairs may be offset from each other. The conductor arrangement, like the arrangement of FIG. **8**A, above, has 36 contacts in 18 signal pairs that are equally divided between IMLAs **1–3** in rows **811–816**. It can be seen that IMLAs **1–3** are in the aforementioned split configuration, where each IMLA has a lengthwise half denoted as A and B. In addition, and as noted above, each contact in a given signal pair is separated by a precisely-maintained distance d, which enables the differential impedance Z_0 to be carefully controlled through the connector.

Unlike the connector of FIG. **8**A, however, the pairs disposed along IMLA **2** are offset from the pairs disposed along IMLAs **1** and **3** by an offset distance o. For comparison, it can be seen that in FIG. **8**A, the IMLAs **1–3** are arranged such that the conductor pairs that comprise each row **811–816** are in alignment. It will be appreciated that the magnitude of the offset distance o in FIG. **8**B may be determined by any number and type of considerations, such as for example the intended application of the connector or the like. In addition, it will be appreciated that any or all of the IMLAs present in a given connector may be offset from any other IMLA within the connector by any offset distance o. In such embodiments, the offset distance o between any two IMLAs may be the same as or different from the offset distance o between any other IMLAs within the connector.

It will be further appreciated that the offset distance o and the distance d may be set so as to achieve a desired differential impedance Z_0. Therefore, while some embodiments may achieve a desired differential impedance Z_0 by precisely maintaining the distance d alone, other embodiments may achieve a desired differential impedance Z_0 by maintaining the distance d in combination with setting one or more offset distances o.

Thus, a method and system for split IMLA impedance control has been disclosed. It is to be understood that the foregoing illustrative embodiments have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the invention. Words which have been used herein are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular structure, materials and/or embodiments, the invention is not intended to be limited to the particulars disclosed herein. Rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the teachings of this specification, may affect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects.

What is claimed:

1. An electrical connector comprising:

a first leadframe housing having a portion of a first electrical contact extending therethrough; and

a second leadframe housing having a portion of a second electrical contact extending therethrough,

wherein the second leadframe housing is disposed adjacent to the first leadframe housing such that an air gap is formed between the respective portions of the electrical contacts that extend through the leadframe housings,

wherein the gap has a gap width that provides for a desired impedance profile between the electrical contacts, and

wherein the impedance profile is a uniform impedance profile along the respective portions of the contacts that extend through the leadframe housings.

2. The electrical connector of claim **1**, wherein the electrical contacts form a differential signal pair.

3. The electrical connector of claim **1**, wherein the electrical contacts are broadside-coupled.

4. The electrical connector of claim **1**, wherein the first leadframe housing is made of an electrically insulating material.

5. The electrical connector of claim **1**, wherein the first leadframe housing is made of a plastic.

6. The electrical connector of claim **1**, wherein the first leadframe housing is insert molded.

7. The electrical connector of claim **1**, wherein the first and second leadframe housings are coupled with an interference fit.

8. The electrical connector of claim **1**, wherein the first leadframe housing has a first recess, and the first electrical contact sits in the first recess, the second leadframe housing has a second recess, and the second electrical contact sits in the second recess.

9. The electrical connector of claim **8**, wherein the first recess has a first depth, the first electrical contact has a first thickness, the second recess has a second depth, and the second electrical contact has a second thickness, and wherein the first and second depths and first and second thicknesses together define the gap width.

10. The electrical connector of claim **1**, wherein the first leadframe housing has a recess, and the first electrical contact sits in the recess.

11. The electrical connector of claim **10**, wherein the gap has a gap width, and the recess has a depth that at least partially defines the gap width.

12. The electrical connector of claim **10**, wherein the first leadframe housing comprises a face that at least partially defines the recess, and the first electrical contact abuts the face.

13. The electrical connector of claim **10**, wherein the first leadframe housing comprises a plurality of faces that collectively define the recess, and the first electrical contact abuts each of the faces.

14. The electrical connector of claim **10**, wherein the second leadframe housing has a recess, and the second electrical contact sits in the recess of the second leadframe housing.

15. The electrical connector of claim **14**, wherein the gap has a gap width, and the recesses have respective depths that at least partially define the gap width.

16. The electrical connector of claim 15, wherein each of the electrical contacts has a respective thickness that at least partially defines the gap width.

17. An electrical connector comprising:

a first lead frame assembly comprising a first leadframe housing, a first signal contact, and a second signal contact adjacent to the first signal contact; and

a second lead frame assembly comprising a second leadframe housing, a third signal contact, and a fourth signal contact adjacent to the third signal contact, the first and third signal contacts forming a first differential signal pair and the second and fourth signal contacts forming a second differential signal pair,

wherein a first air gap is formed between respective portions of the first and third signal contacts that extend through the respective leadframe housings, and a second air gap is formed between respective portions of the second and fourth signal contacts that extend through the respective leadframe housings

wherein the first air gap has a gap width that provides for a uniform impedance profile along the respective portions of the first and third contacts that extend through the respective leadframe housings.

18. The electrical connector of claim 17, wherein the air gaps have respective gap widths that limit cross-talk between the differential signal pairs.

19. The electrical connector of claim 17, wherein the connector is a mezzanine-style electrical connector.

20. The electrical connector of claim 17, wherein the differential signal pairs are broadside-coupled.

21. The electrical connector of claim 17, wherein the connector is devoid of shields between adjacent differential signal pairs.

22. The electrical connector of claim 17, wherein the first air gap has a gap width that limits interference from the first differential signal pair at the second differential signal pair.

23. The electrical connector of claim 22, wherein the second air gap has a second gap width that limits interference from the second differential signal pair at the first differential signal pair.

24. The electrical connector of claim 23, wherein the first leadframe housing has a first and second recess, and the second leadframe housing has a third and fourth recess, and wherein the first, second, third and fourth signal contacts sit in the first, second, third, and fourth recesses, respectively.

25. The electrical connector of claim 24, wherein the first, second, third, and fourth recesses have first, second, third and fourth depths, respectively, and wherein the first, second, third, and fourth signal contacts have first, second, third, and fourth thicknesses, respectively.

26. The electrical connector of claim 25, wherein the first depth and thickness and the third depth and thickness together define the first gap width.

27. The electrical connector of claim 25, wherein the second depth and thickness and the fourth depth and thickness together define the second gap width.

28. An electrical connector comprising:

a first leadframe housing having a portion of a first electrical contact extending therethrough; and

a second leadframe housing having a portion of a second electrical contact extending therethrough,

wherein an air gap is formed between the respective portions of the electrical contacts that extend through the leadframe housings, the gap having a gap width that provides for a desired impedance profile between the electrical contacts,

wherein the impedance profile is a uniform impedance profile along the respective portions of the contacts that extend through the leadframe housings.

29. The electrical connector of claim 28, wherein the first leadframe housing has a first recess, and the first electrical contact sits in the first recess.

30. The electrical connector of claim 29, wherein the second leadframe housing has a second recess, and the second electrical contact sits in the second recess.

31. The electrical connector of claim 30, wherein the first and second recesses have a first and second depths, respectively, and the first and second electrical contacts have a first and second thicknesses, respectively, and the first and second depths and the first and second thicknesses together define the gap width.

* * * * *

Exhibit B

US007114964B2

(12) **United States Patent**
Winings et al.

(10) **Patent No.: US 7,114,964 B2**
(45) **Date of Patent: Oct. 3, 2006**

(54) **CROSS TALK REDUCTION AND IMPEDANCE MATCHING FOR HIGH SPEED ELECTRICAL CONNECTORS**

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(73) Assignee: **FCI Americas Technology, Inc.**, Reno, NV (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/052,167**

(22) Filed: **Feb. 7, 2005**

(65) **Prior Publication Data**

US 2005/0287849 A1 Dec. 29, 2005

Related U.S. Application Data

(63) Continuation of application No. 10/294,966, filed on Nov. 14, 2002, now Pat. No. 6,976,886, which is a continuation-in-part of application No. 10/155,786, filed on May 24, 2002, now Pat. No. 6,652,318, which is a continuation-in-part of application No. 09/990,794, filed on Nov. 14, 2001, now Pat. No. 6,692,272.

(51) **Int. Cl.**
H05K 1/00 (2006.01)

(52) **U.S. Cl.** **439/79**; 439/701; 439/608

(58) **Field of Classification Search** 439/701, 439/108, 608, 79
See application file for complete search history.

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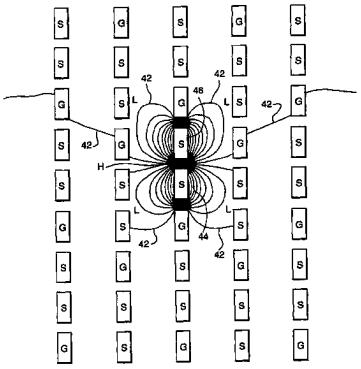
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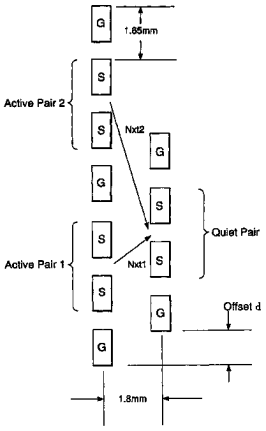
Primary Examiner—Ross Gushi
(74) *Attorney, Agent, or Firm*—Woodcock Washburn LLP

(57) **ABSTRACT**

Lightweight, low-cost, high-density electrical connectors are disclosed that provide impedance-controlled, high-speed, low-interference communications, even in the absence of shields between the contacts, and that provide for a variety of other benefits not found in prior art connectors. An example of such an electrical connector may include a first signal contact positioned within a first linear array of electrical contacts and a second signal contact positioned within a second linear array of electrical contacts that is adjacent to the first linear array. Either of the signal contacts may be a single-ended signal conductor, or one of a differential signal pair. The connector may be devoid of shields between the signal contacts, and of ground contacts adjacent to the signal contacts.

56 Claims, 38 Drawing Sheets





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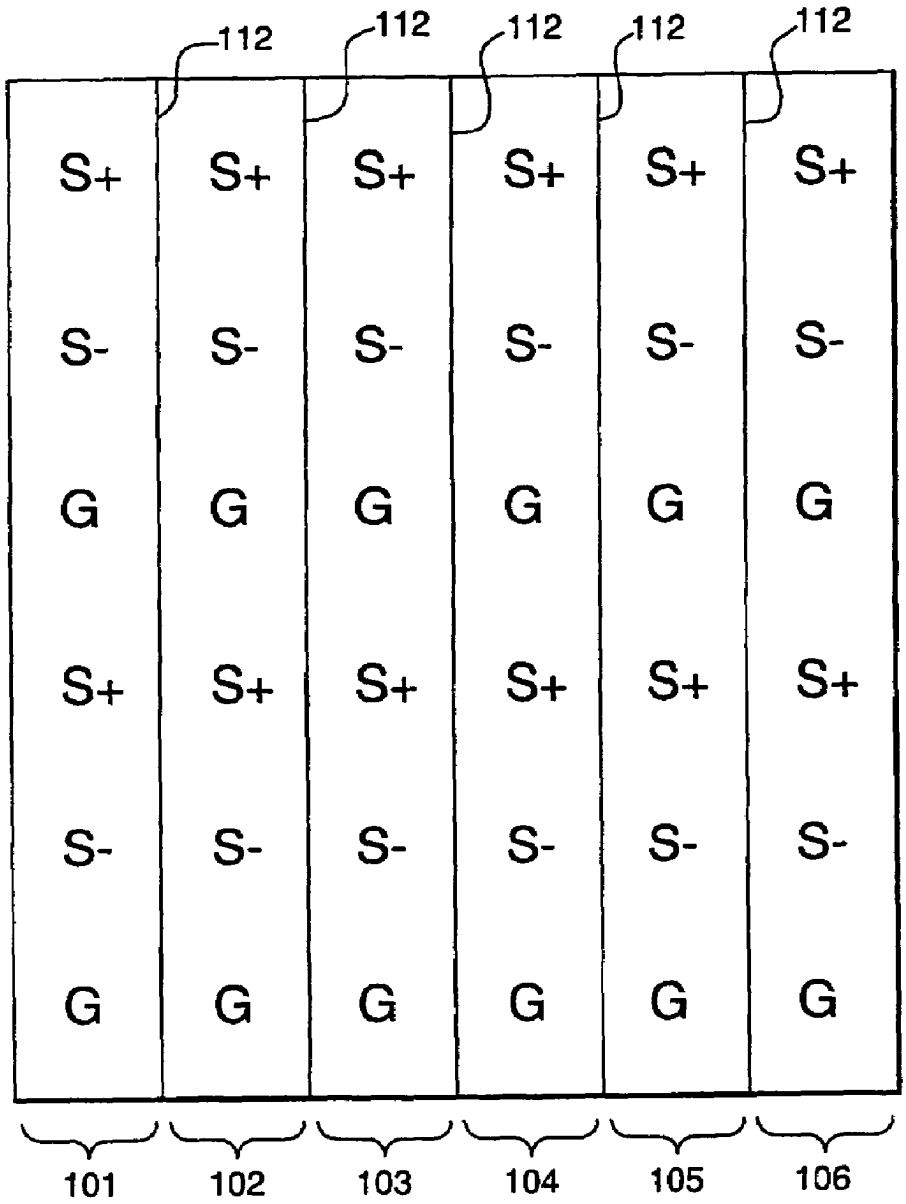


FIG. 1A
(PRIOR ART)

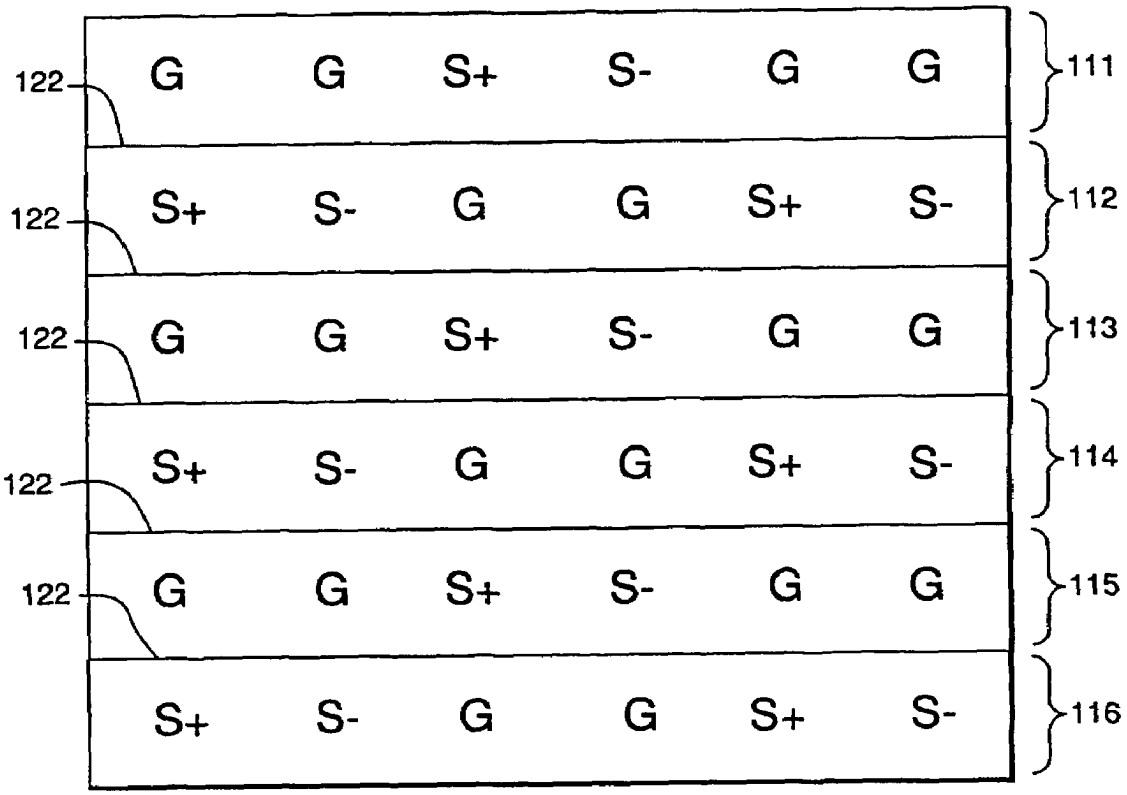


FIG. 1B
(PRIOR ART)

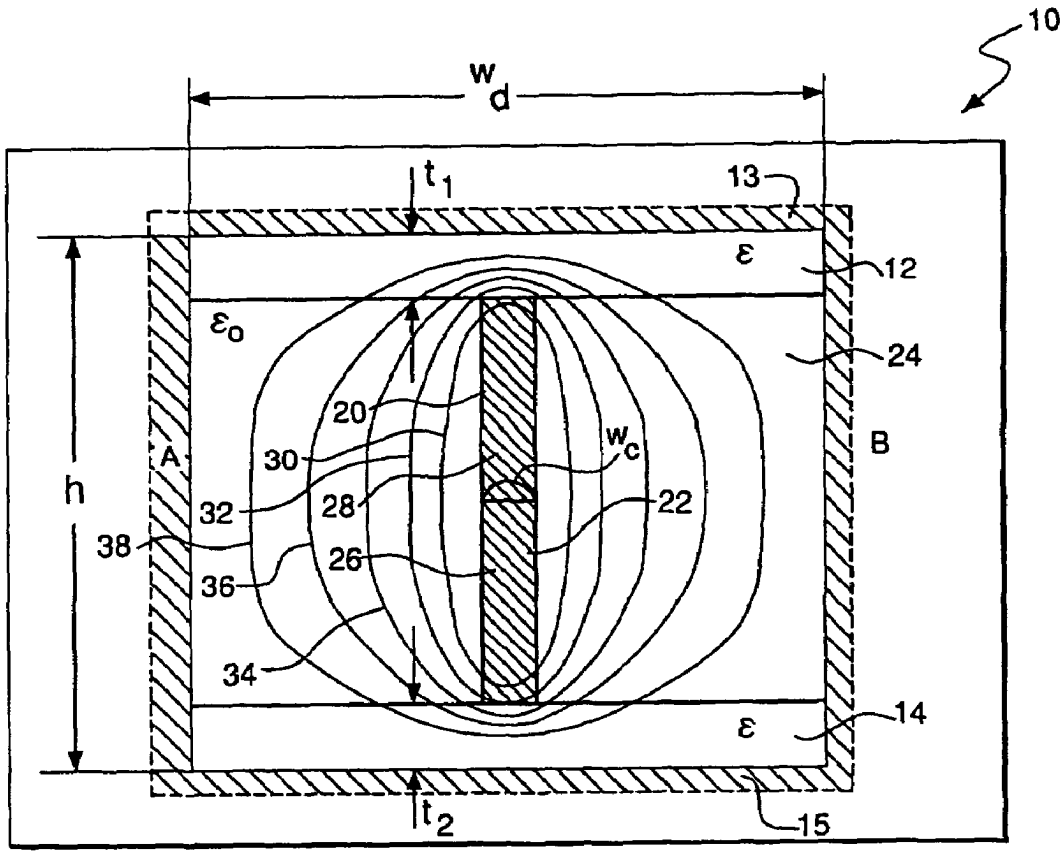


FIG. 2A
(PRIOR ART)

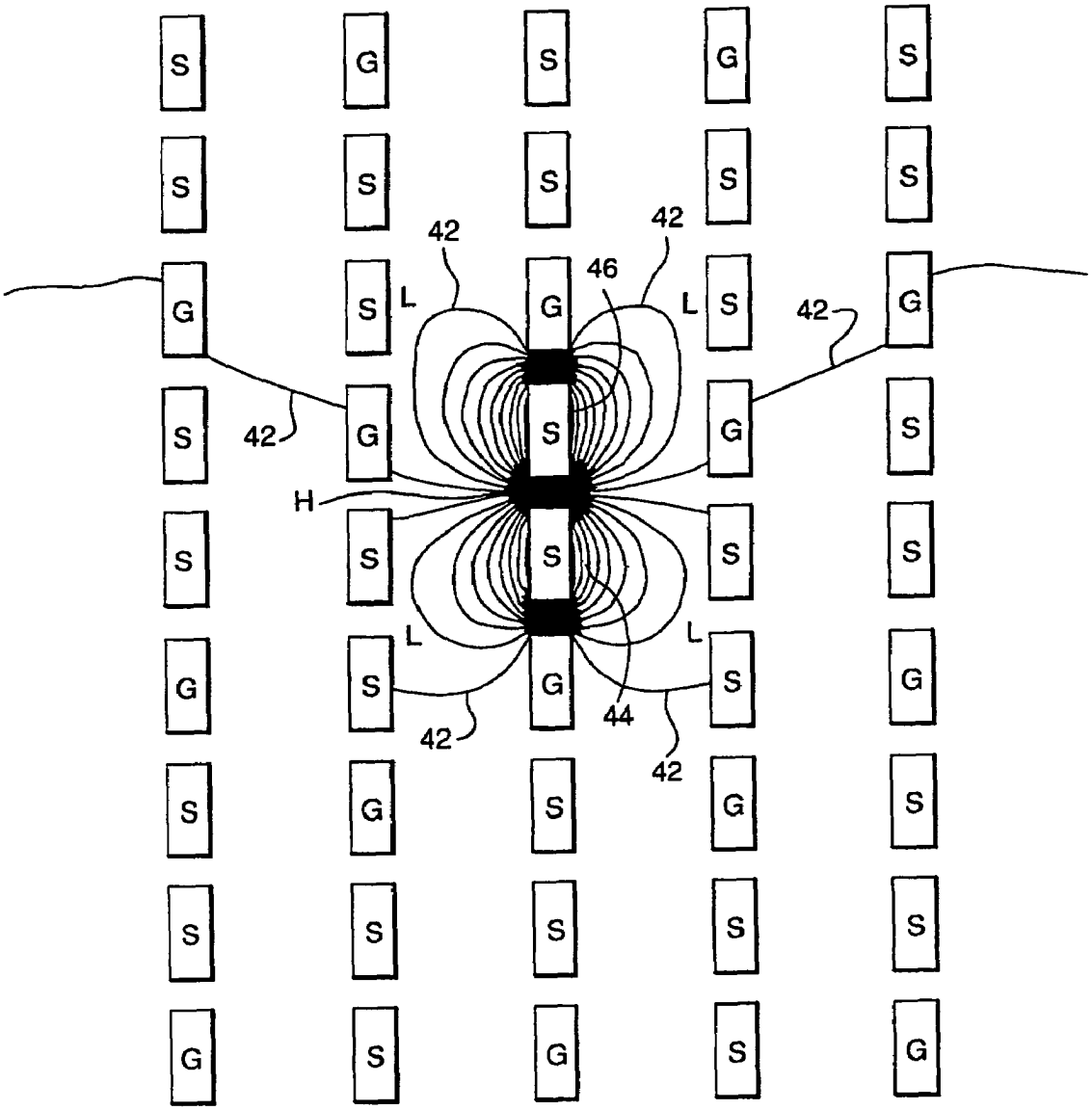


FIG. 2B

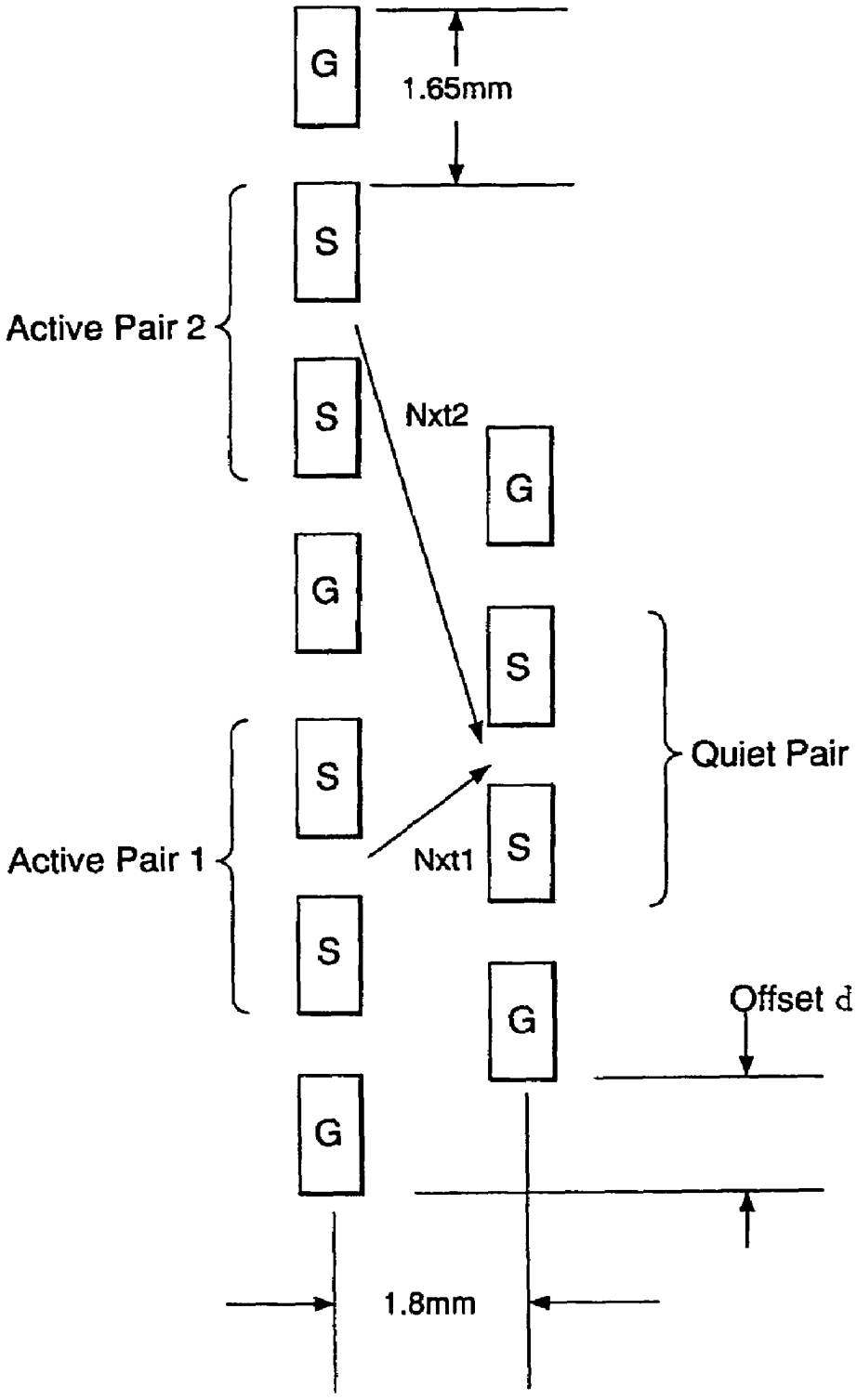

G
1.65mm
S
Active Pair 2
S
Nxt2
G
G
S
Quiet Pair
S
Active Pair 1
Nxt1
S
S
G
Offset d
G
1.8mm

FIG. 3A

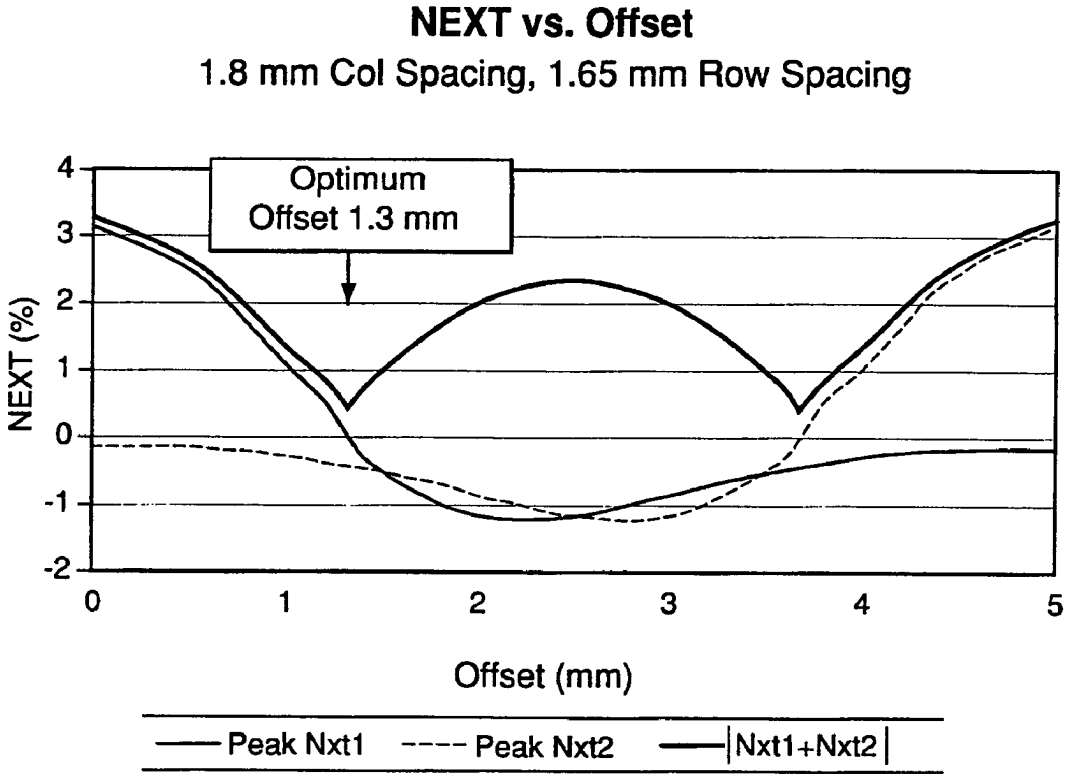

NEXT vs. Offset
1.8 mm Col Spacing, 1.65 mm Row Spacing
Optimum
Offset 1.3 mm
NEXT (%)
4
3
2
1
0
-1
-2
0
1
2
3
4
5
Offset (mm)
Peak Nxt1
Peak Nxt2
|Nxt1+Nxt2|

FIG. 3B

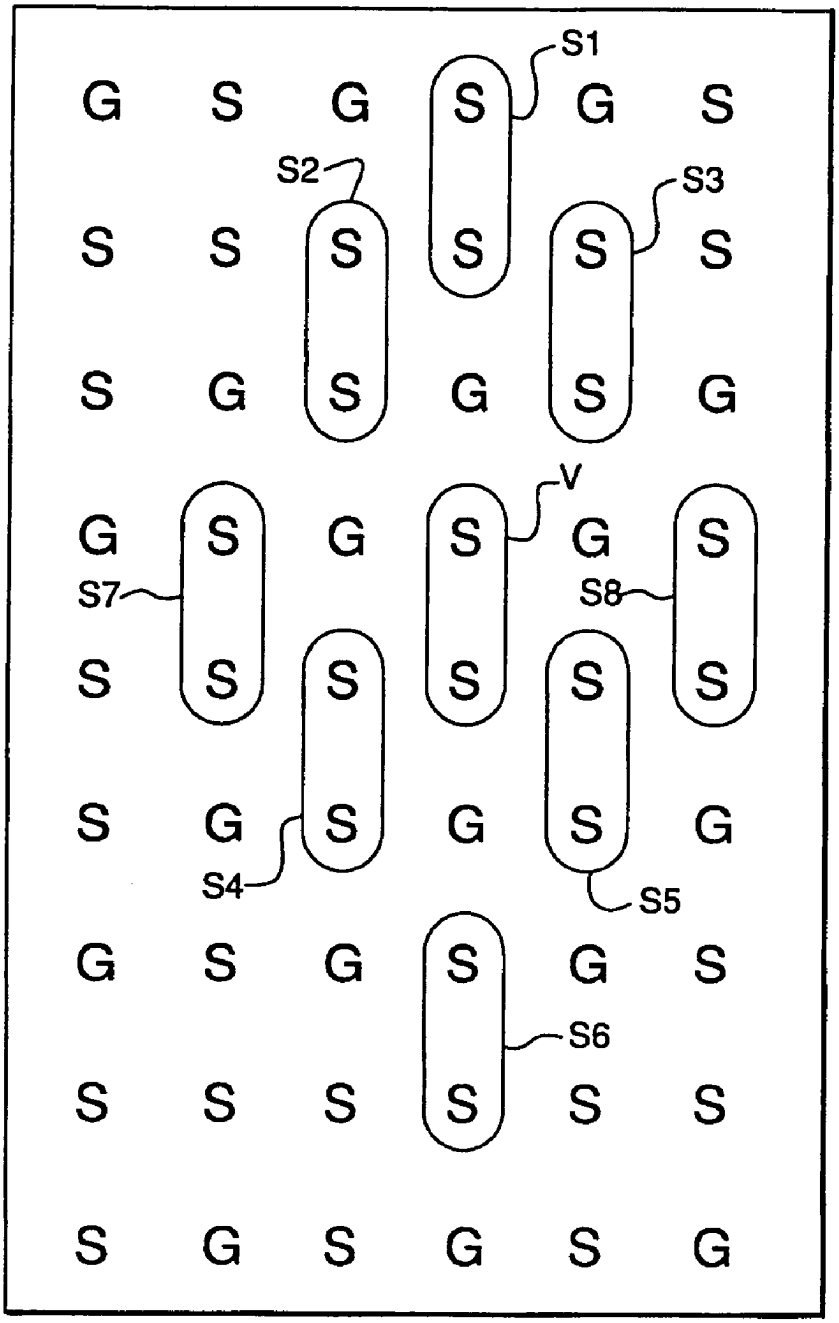


FIG. 3C

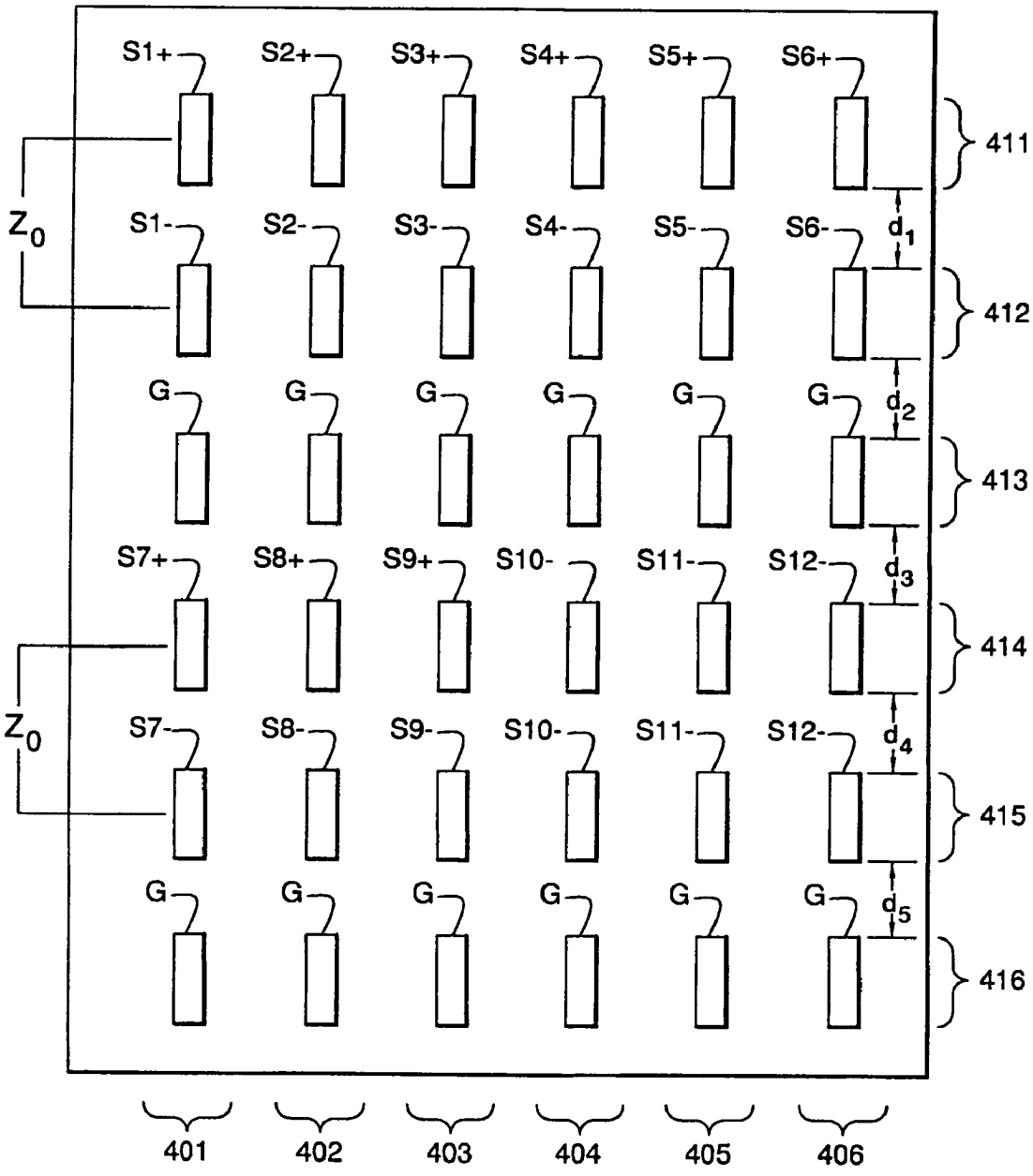

S1+
S2+
S3+
S4+
S5+
S6+
411
Z_0
S1-
S2-
S3-
S4-
S5-
S6-
d_1
412
G
d_2
413
S7+
S8+
S9+
S10-
S11-
S12-
d_3
414
Z_0
S7-
S8-
S9-
S10-
S11-
S12-
d_4
415
d_5
416
401
402
403
404
405
406

FIG. 4A

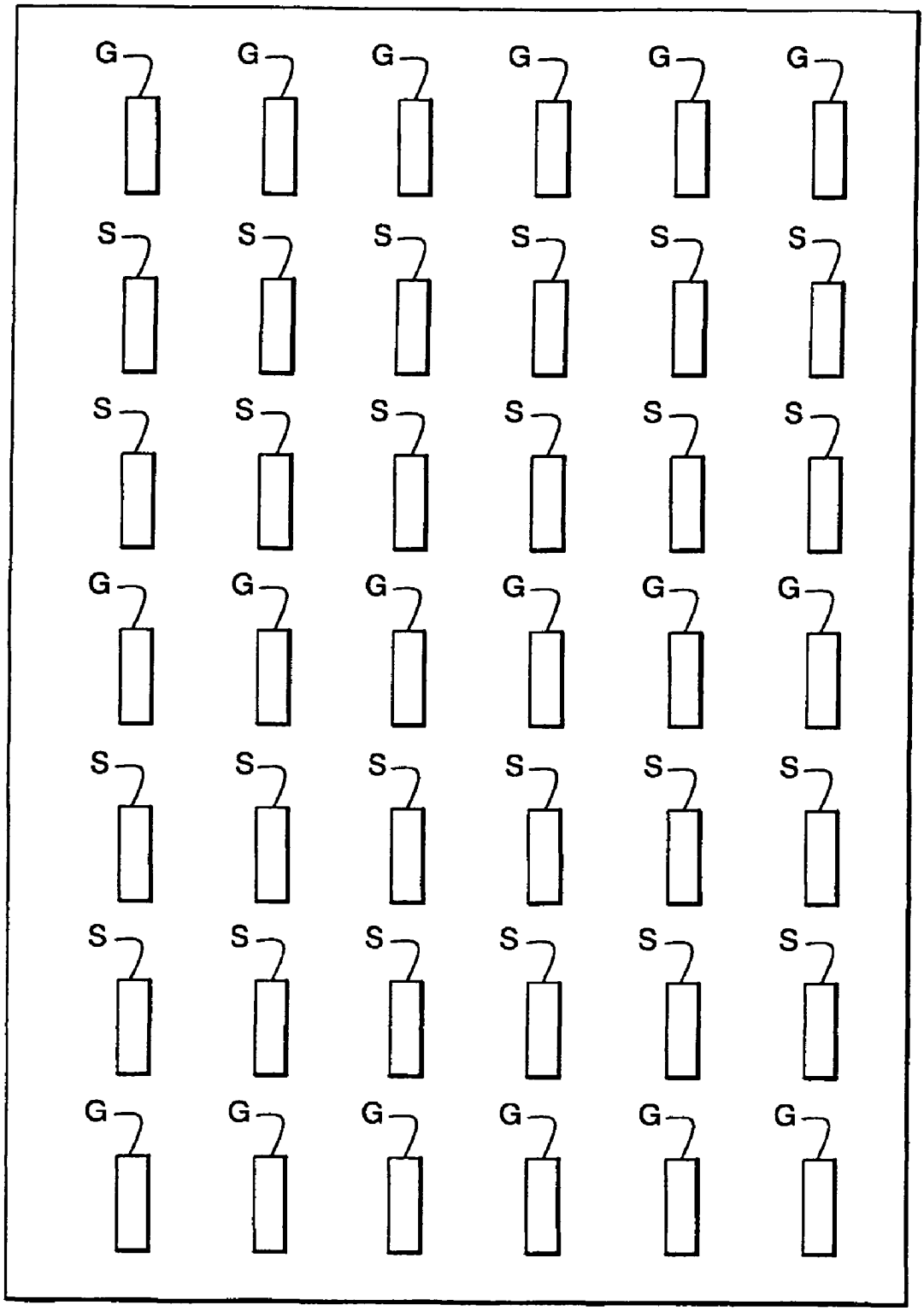


FIG. 4B

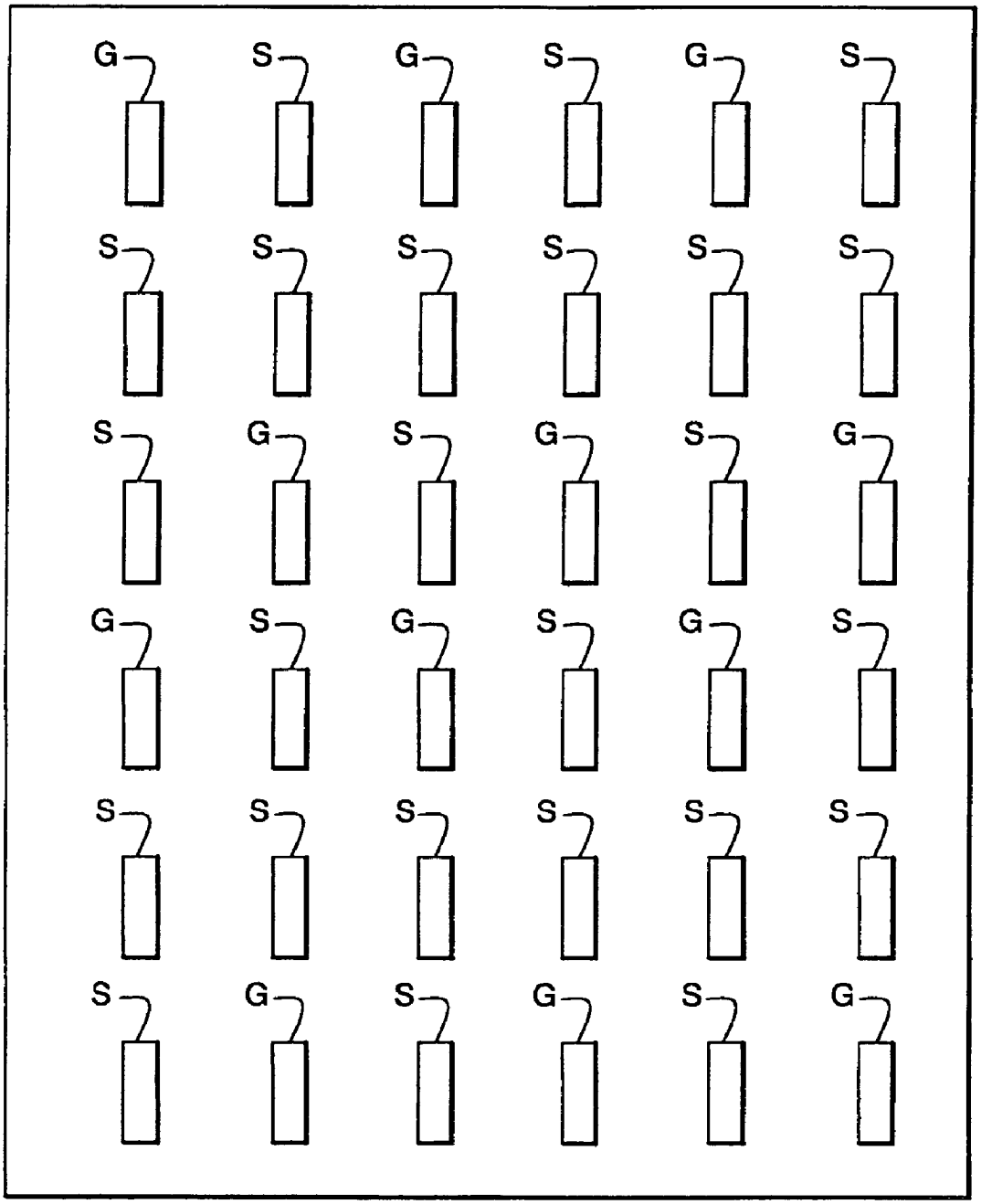


FIG. 4C

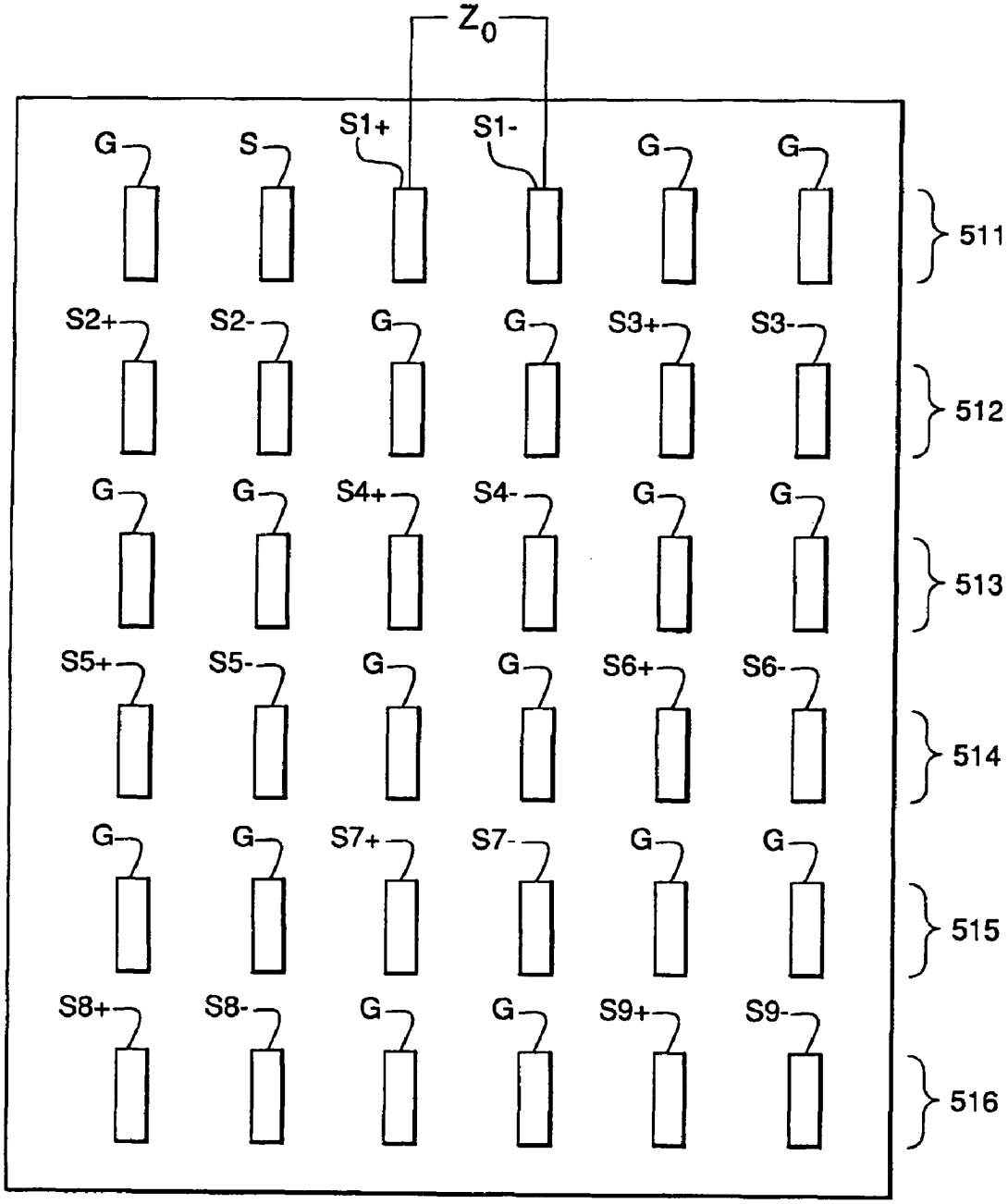

Z_0
G
S
S1+
S1-
G
G
511
S2+
S2-
G
G
S3+
S3-
512
G
G
S4+
S4-
G
G
513
S5+
S5-
G
G
S6+
S6-
514
G
G
S7+
S7-
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G
515
S8+
S8-
G
G
S9+
S9-
516

FIG. 5

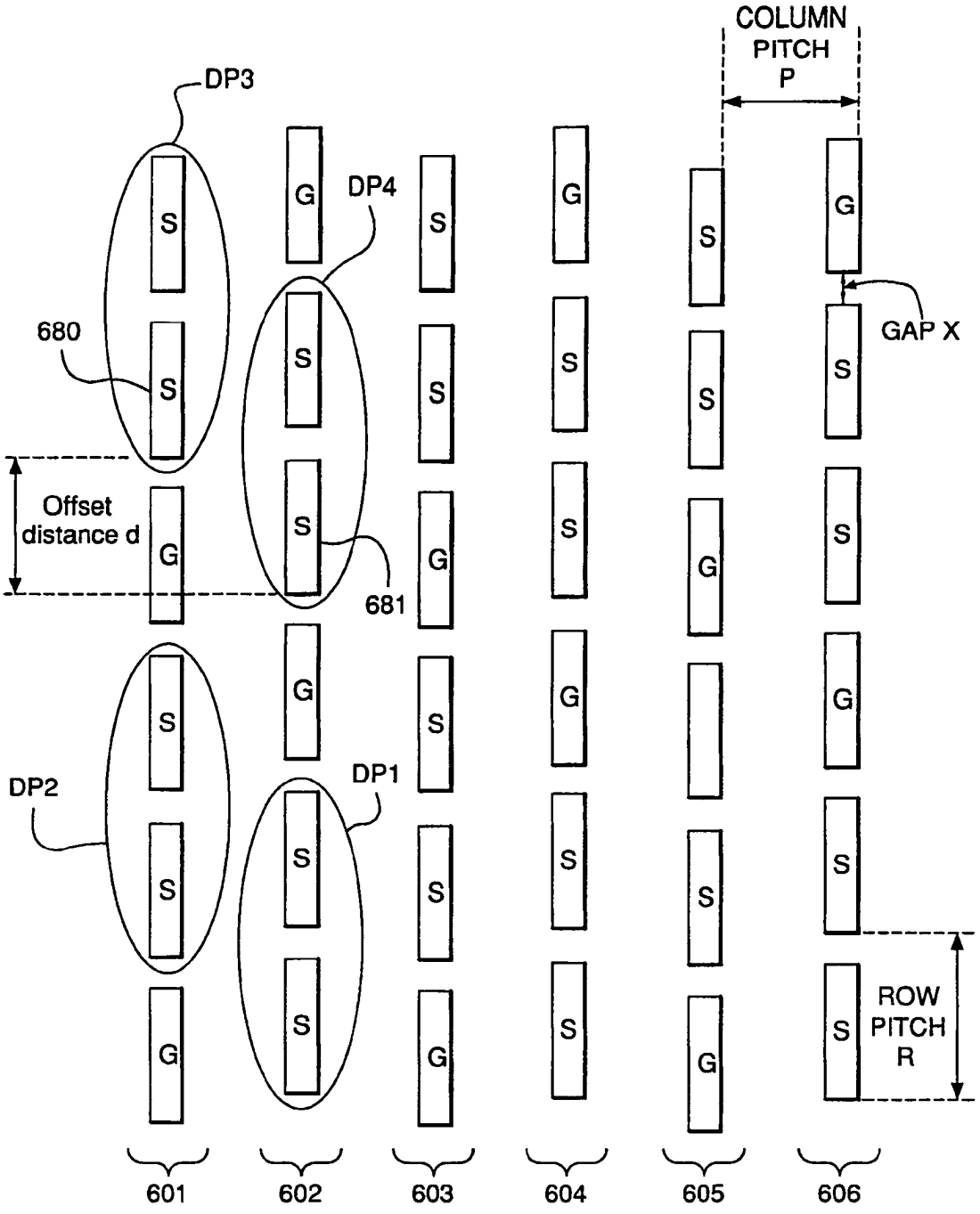

COLUMN
PITCH
P
DP3
DP4
680
GAP X
Offset
distance d
681
DP2
DP1
ROW
PITCH
R
S
G
601
602
603
604
605
606

FIG. 6

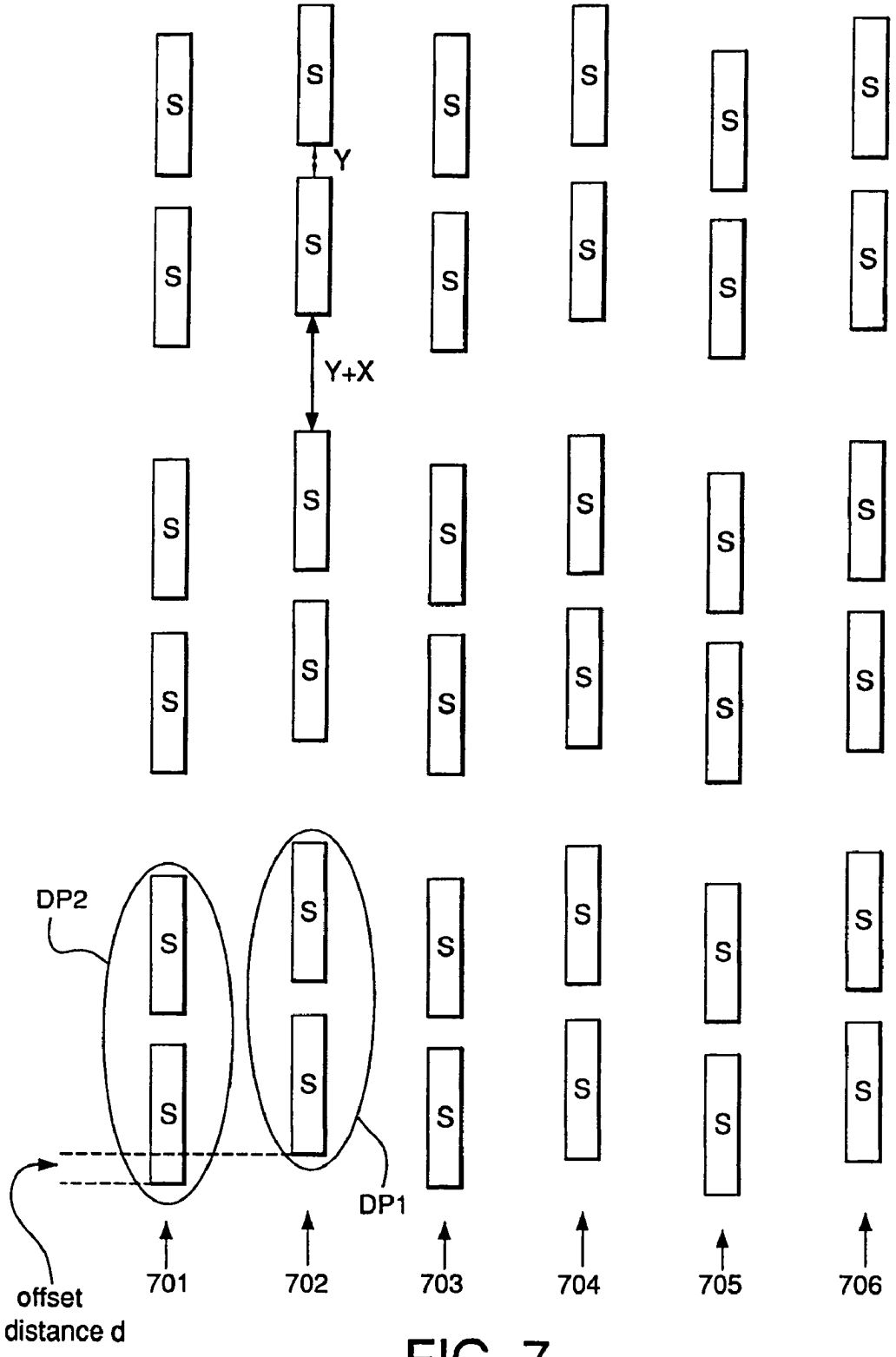


FIG. 7

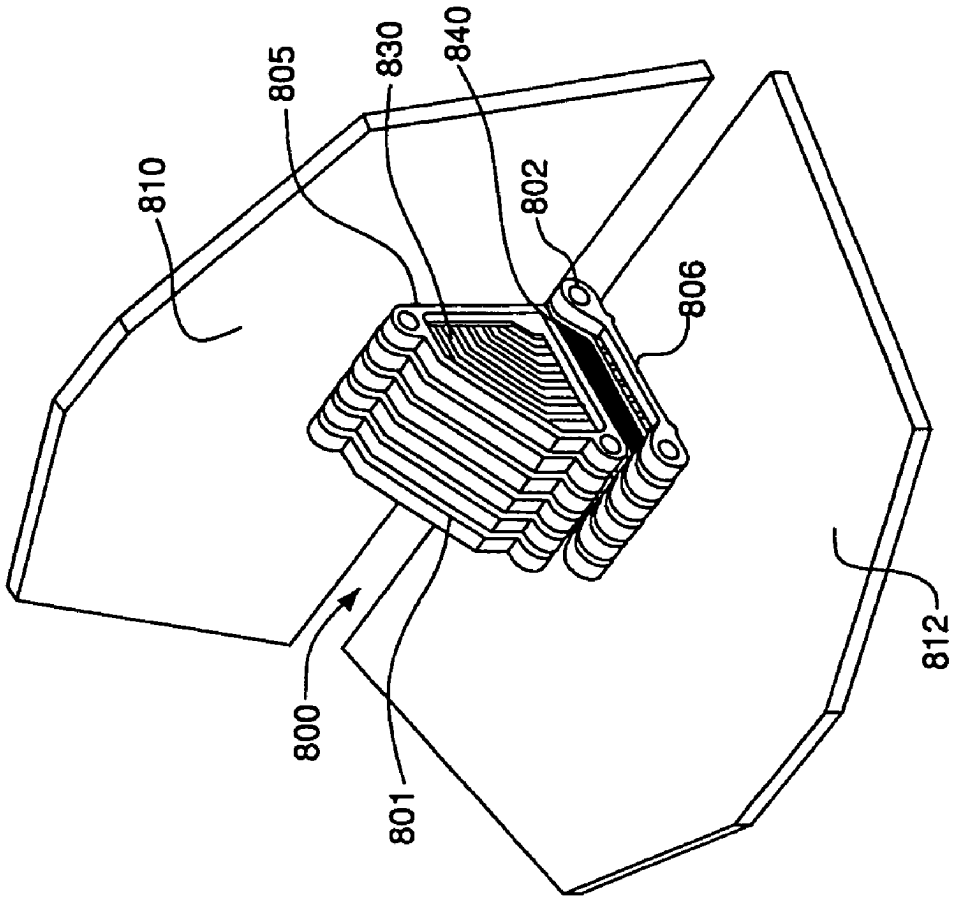


FIG. 8

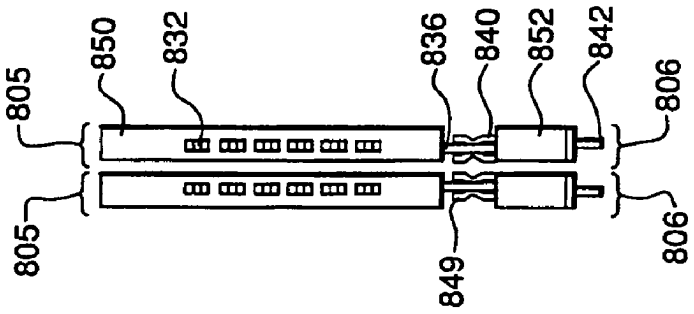


FIG. 10

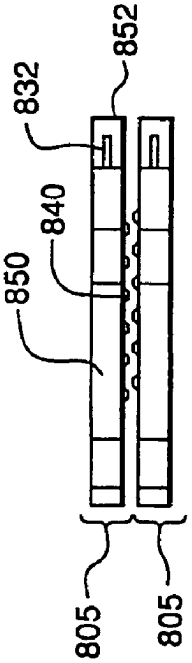


FIG. 11

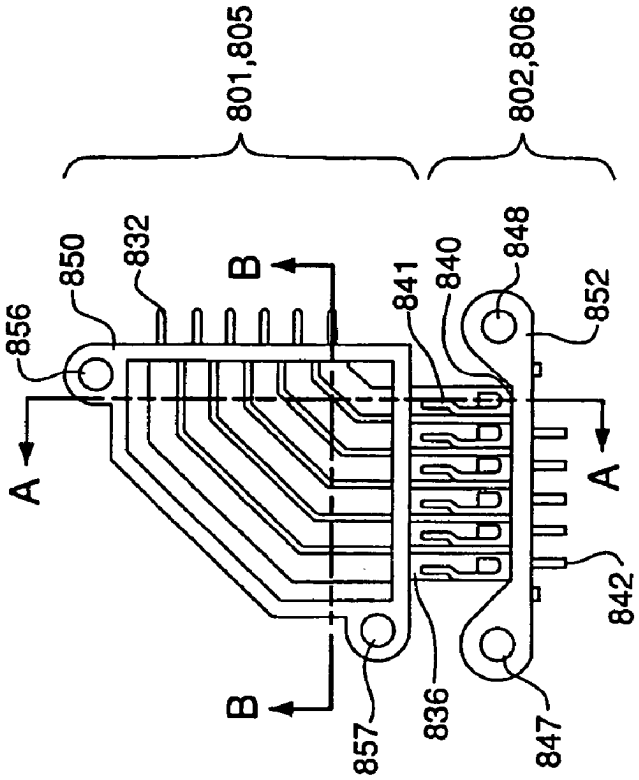


FIG. 9

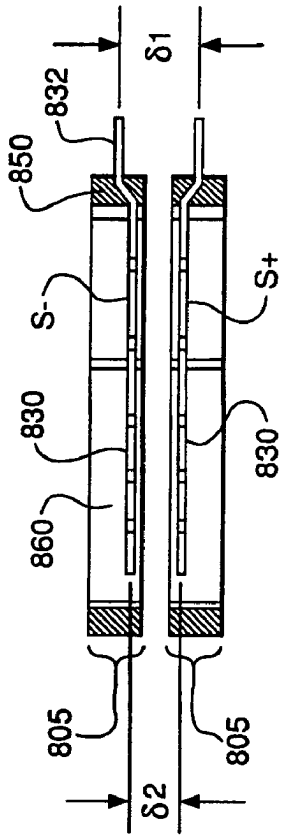


FIG. 12

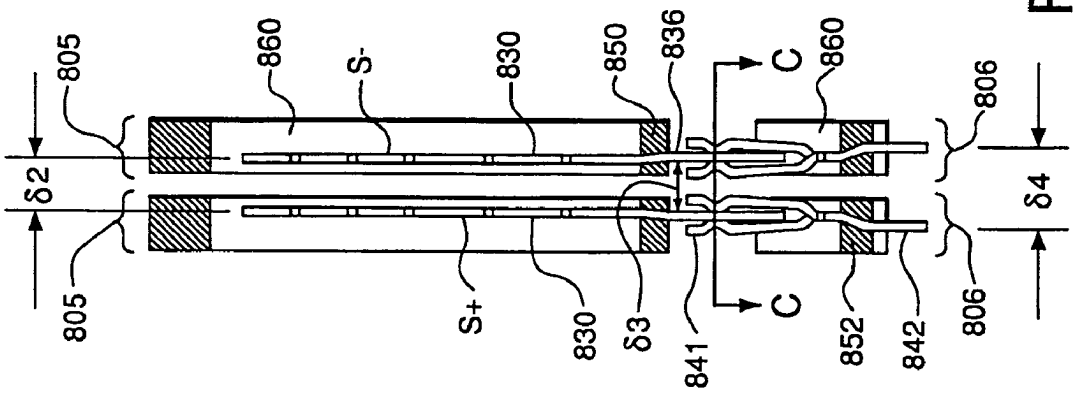


FIG. 13A

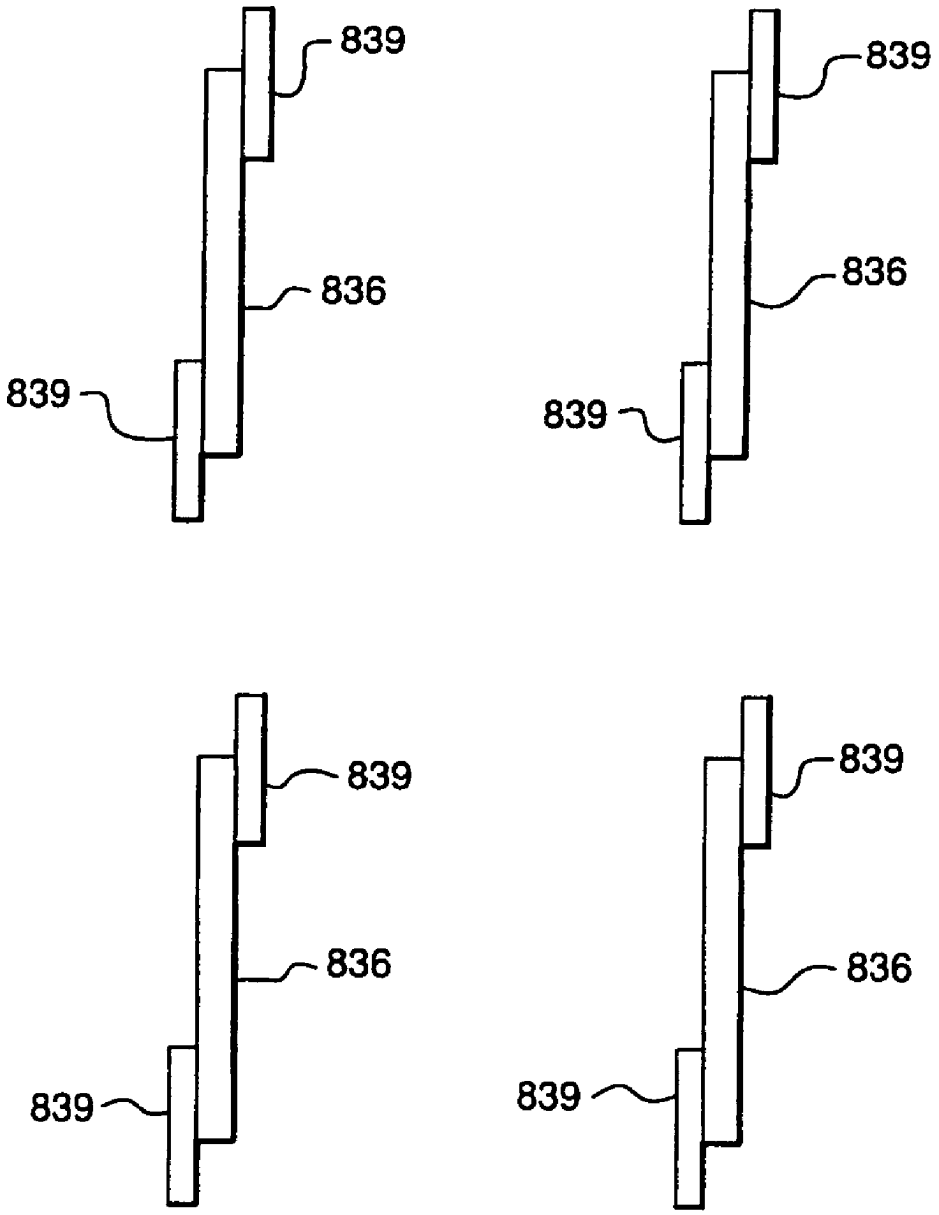


FIG. 13B

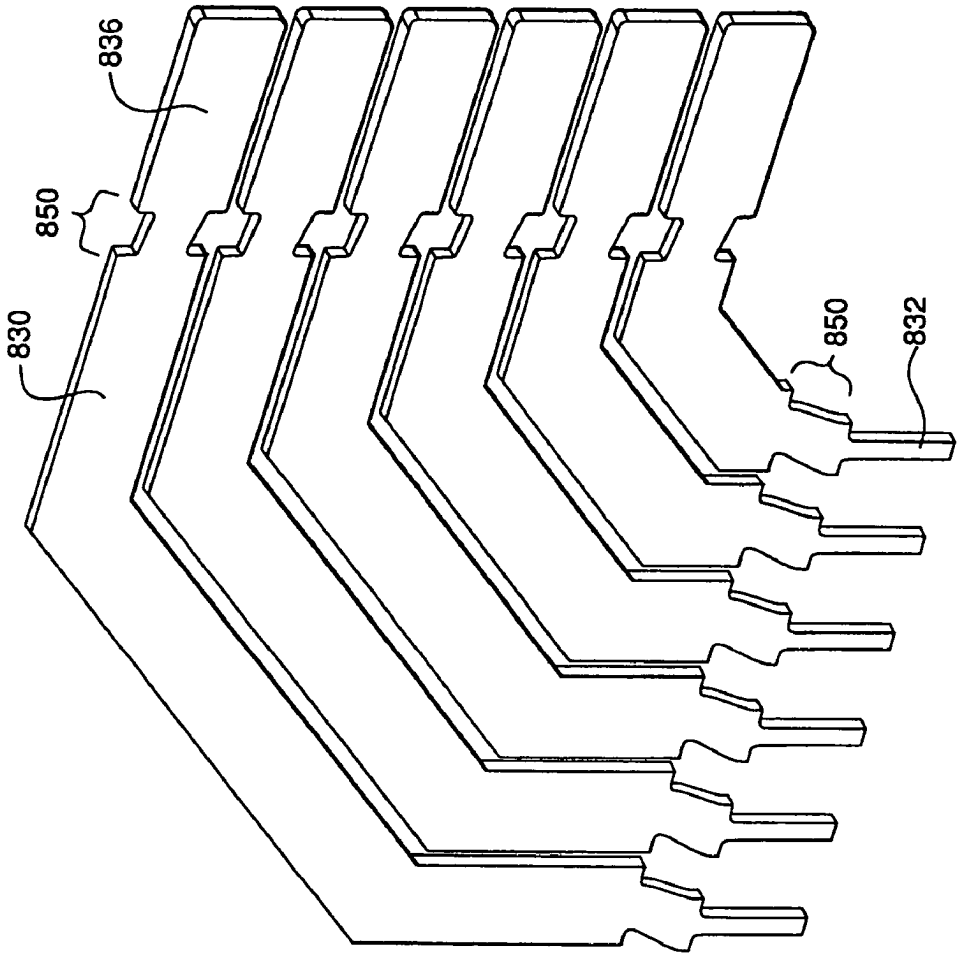


FIG. 14

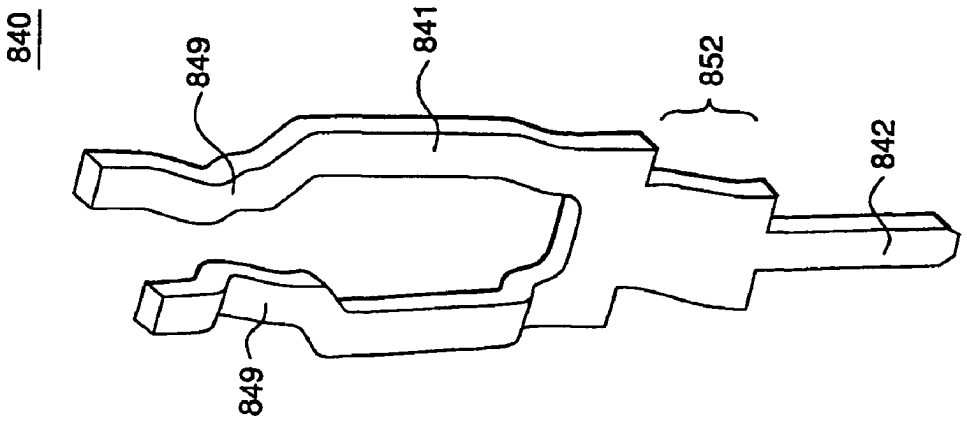


FIG. 15

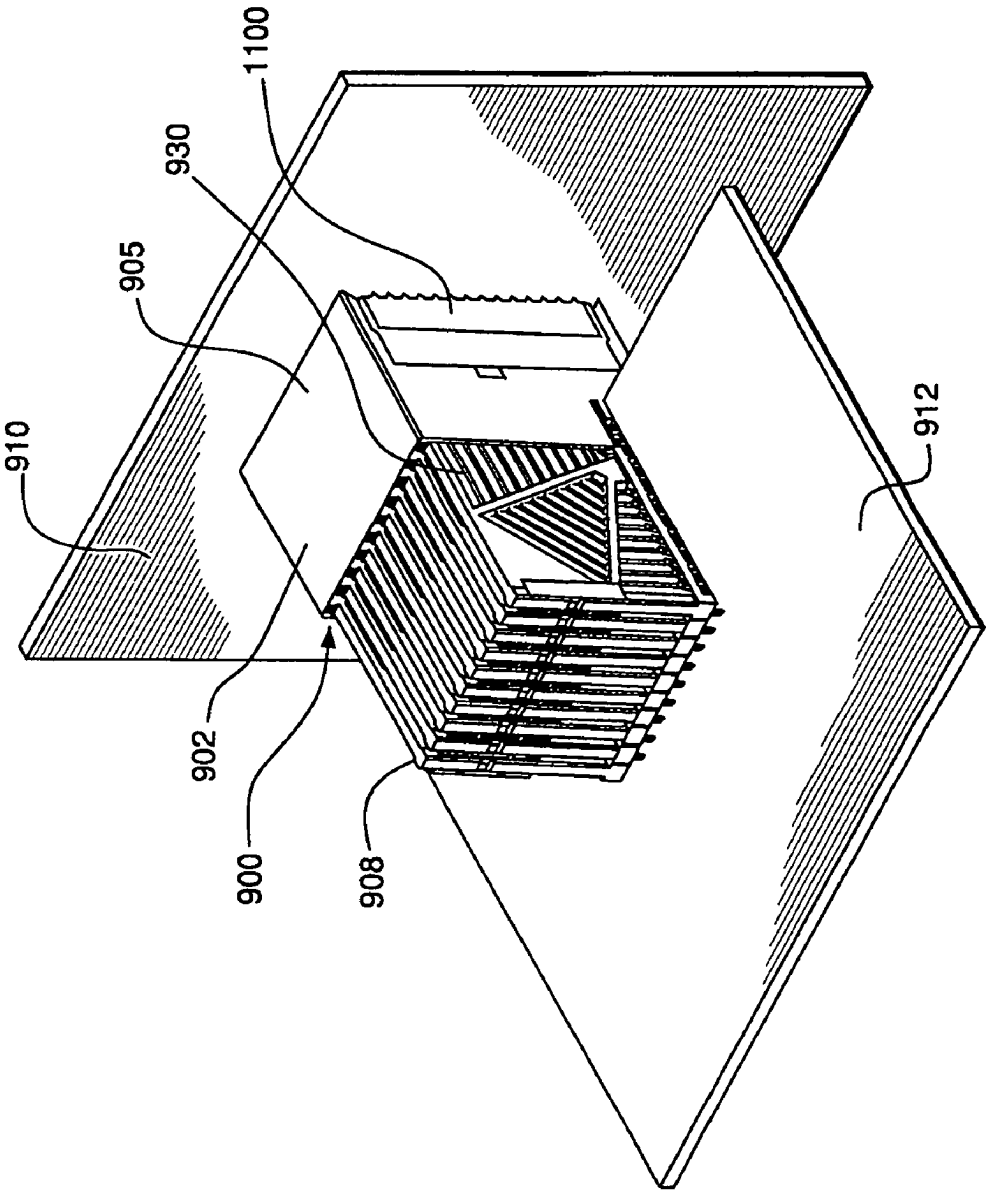


FIG. 16A

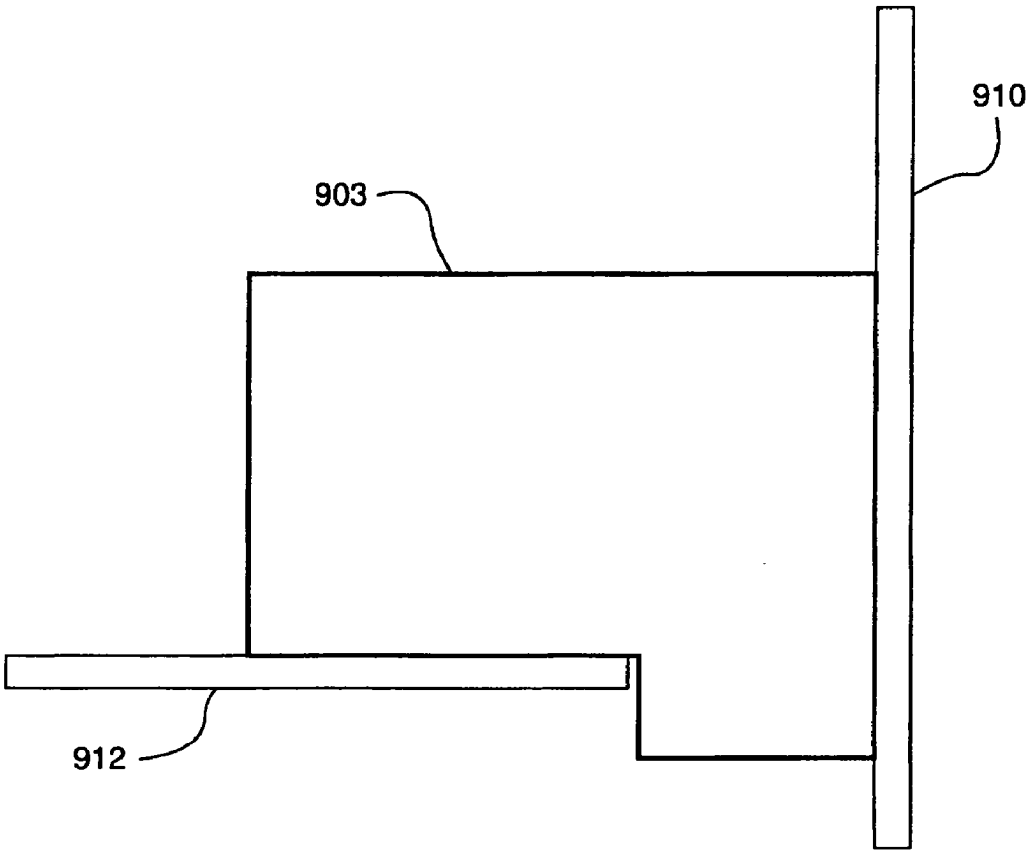


FIG. 16B

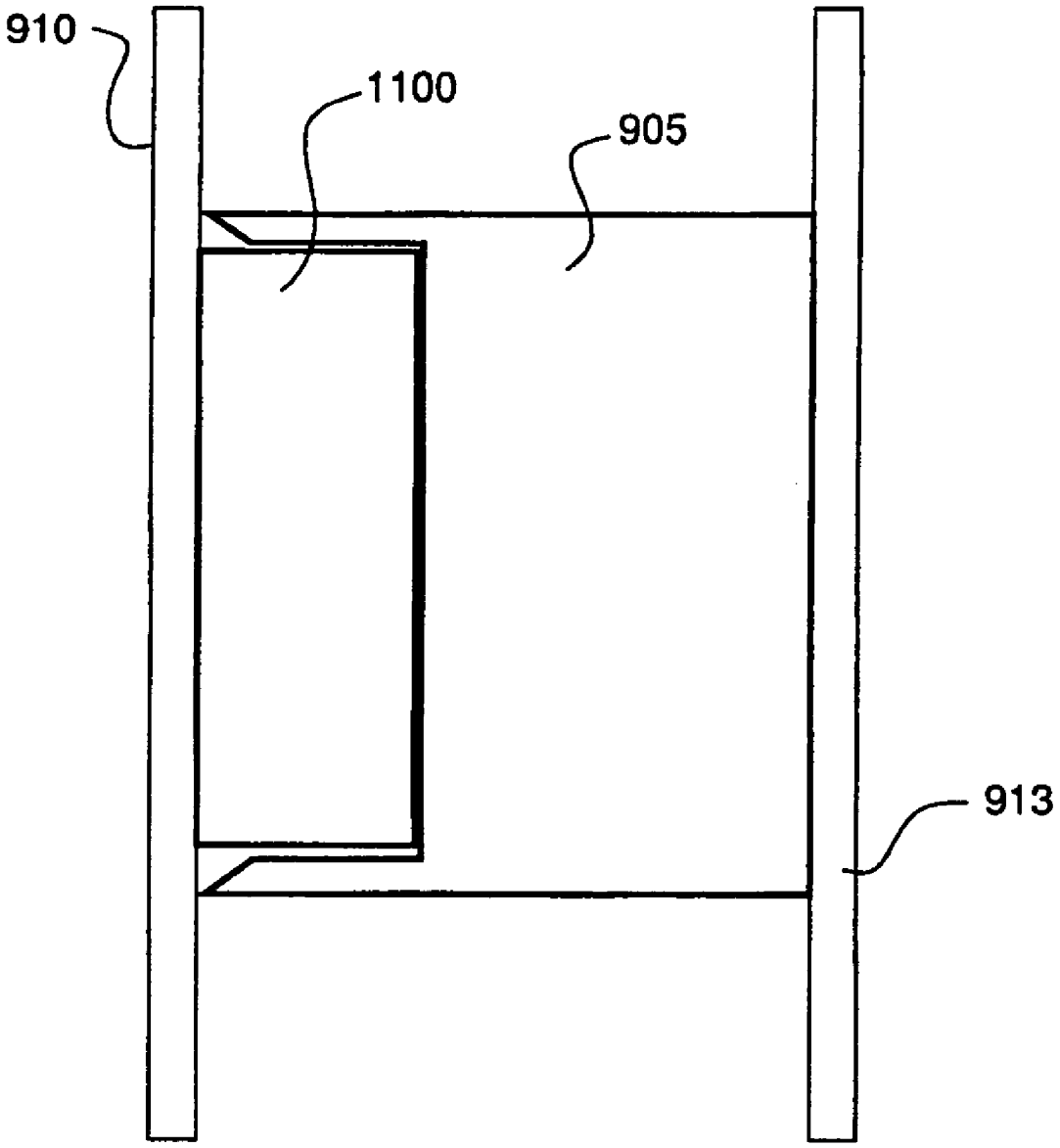


FIG. 16C

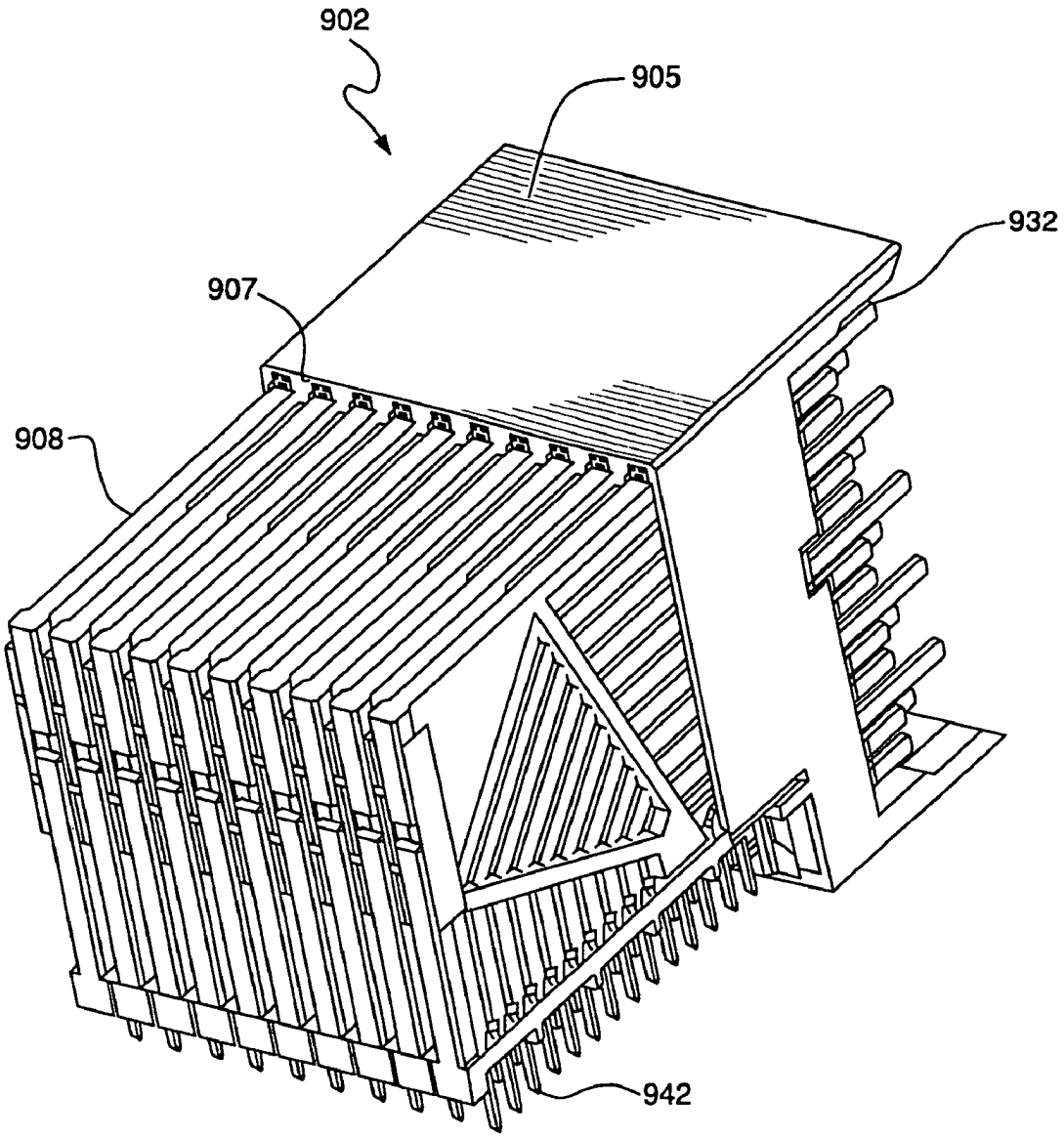


FIG. 17

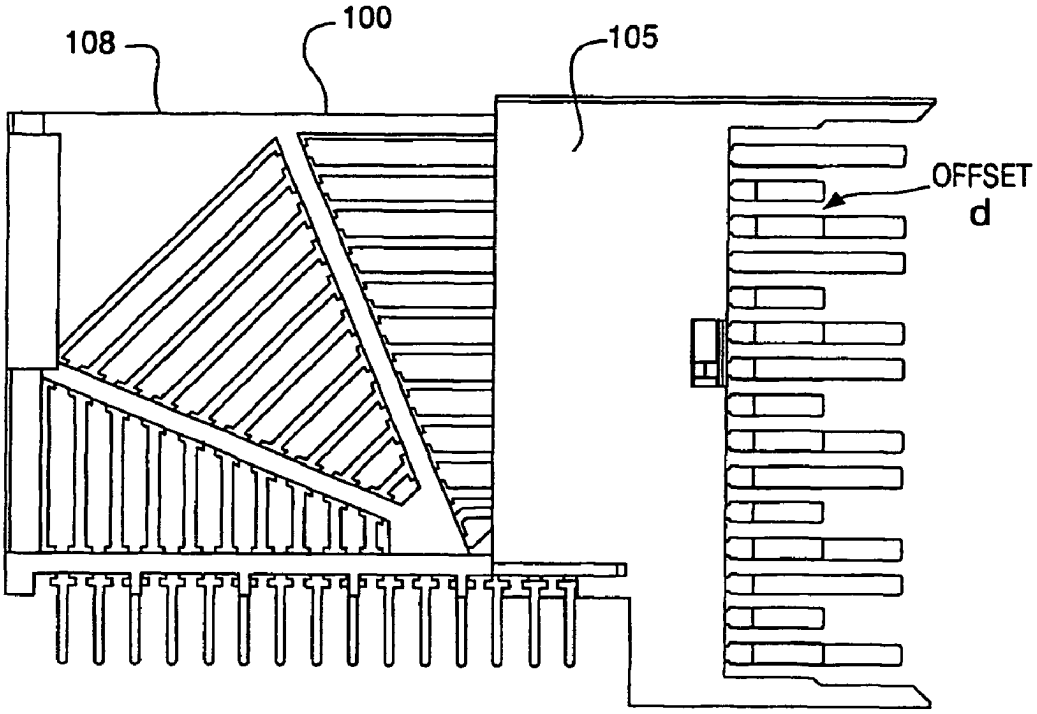


FIG. 18

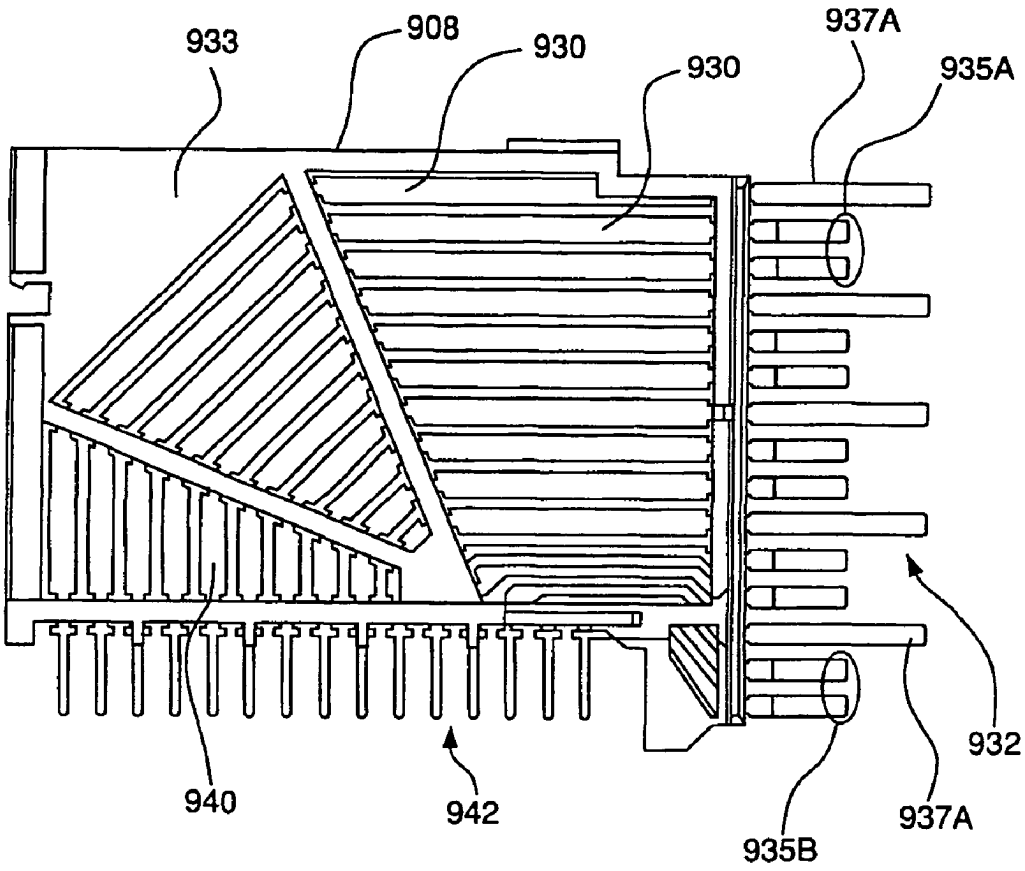


FIG. 19A

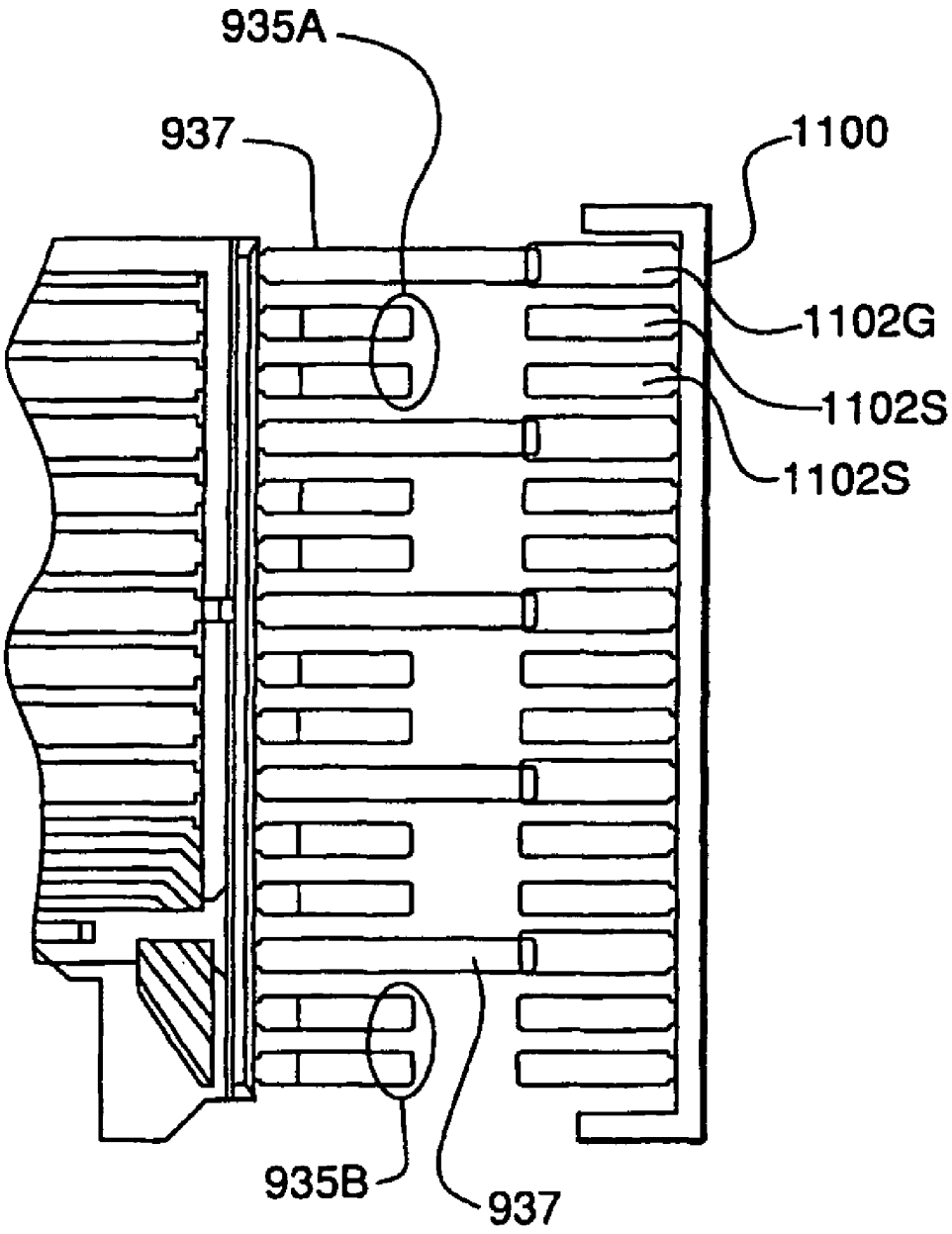


FIG. 19B

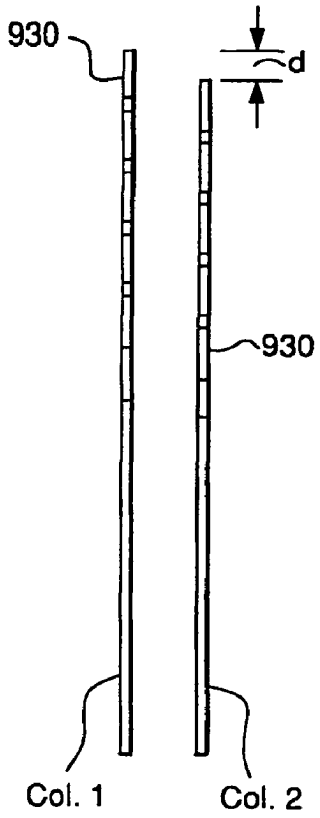


FIG. 20

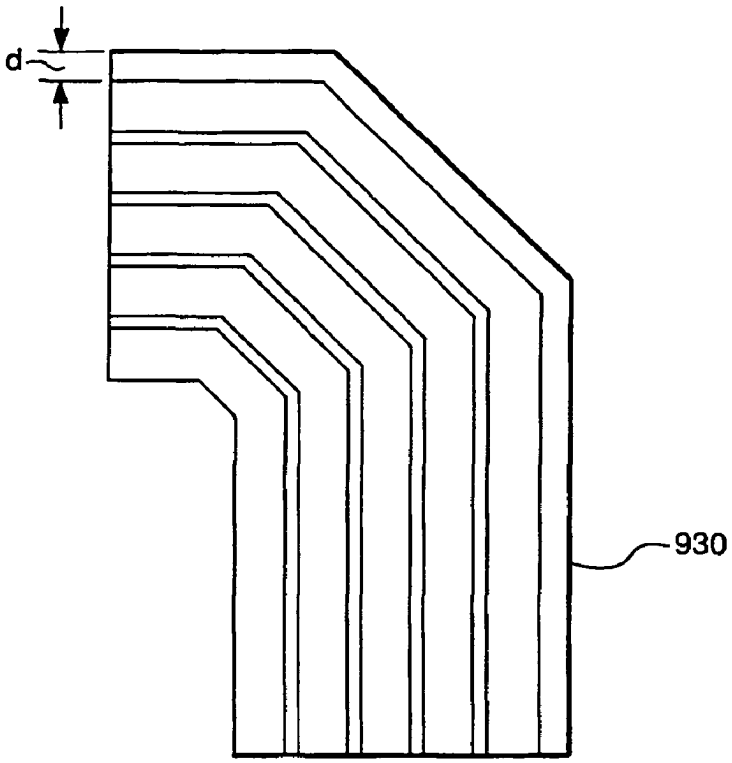


FIG. 21

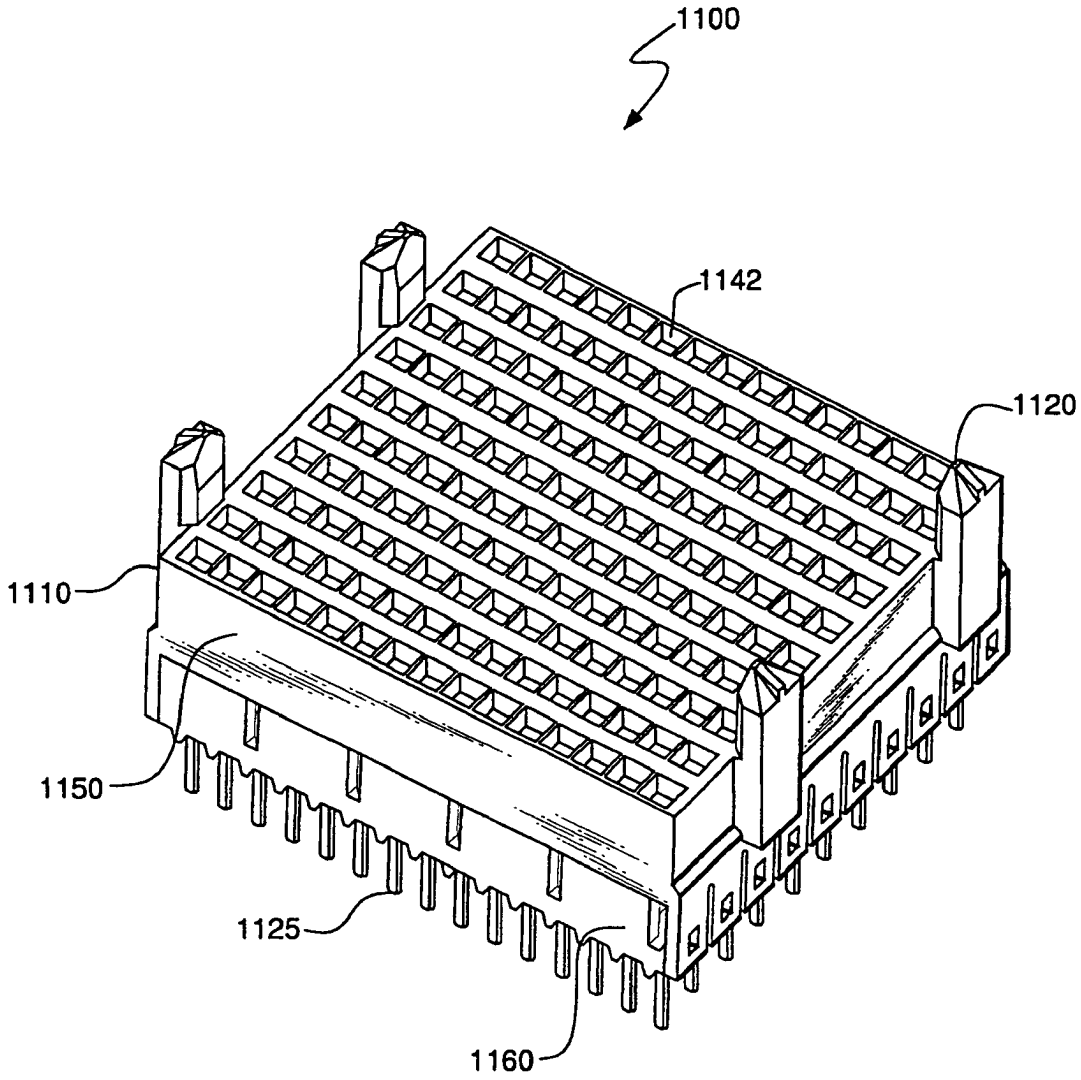


FIG. 22

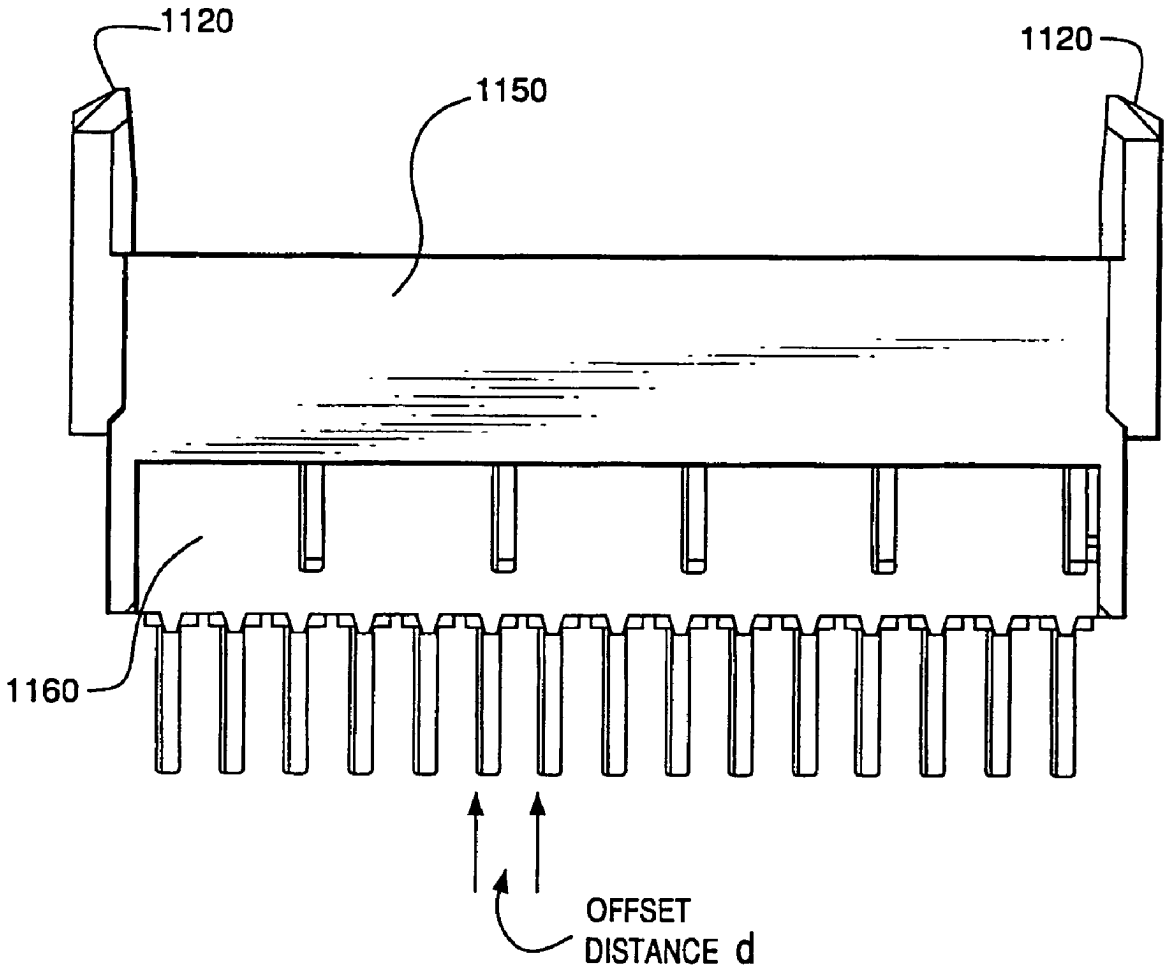


FIG. 23

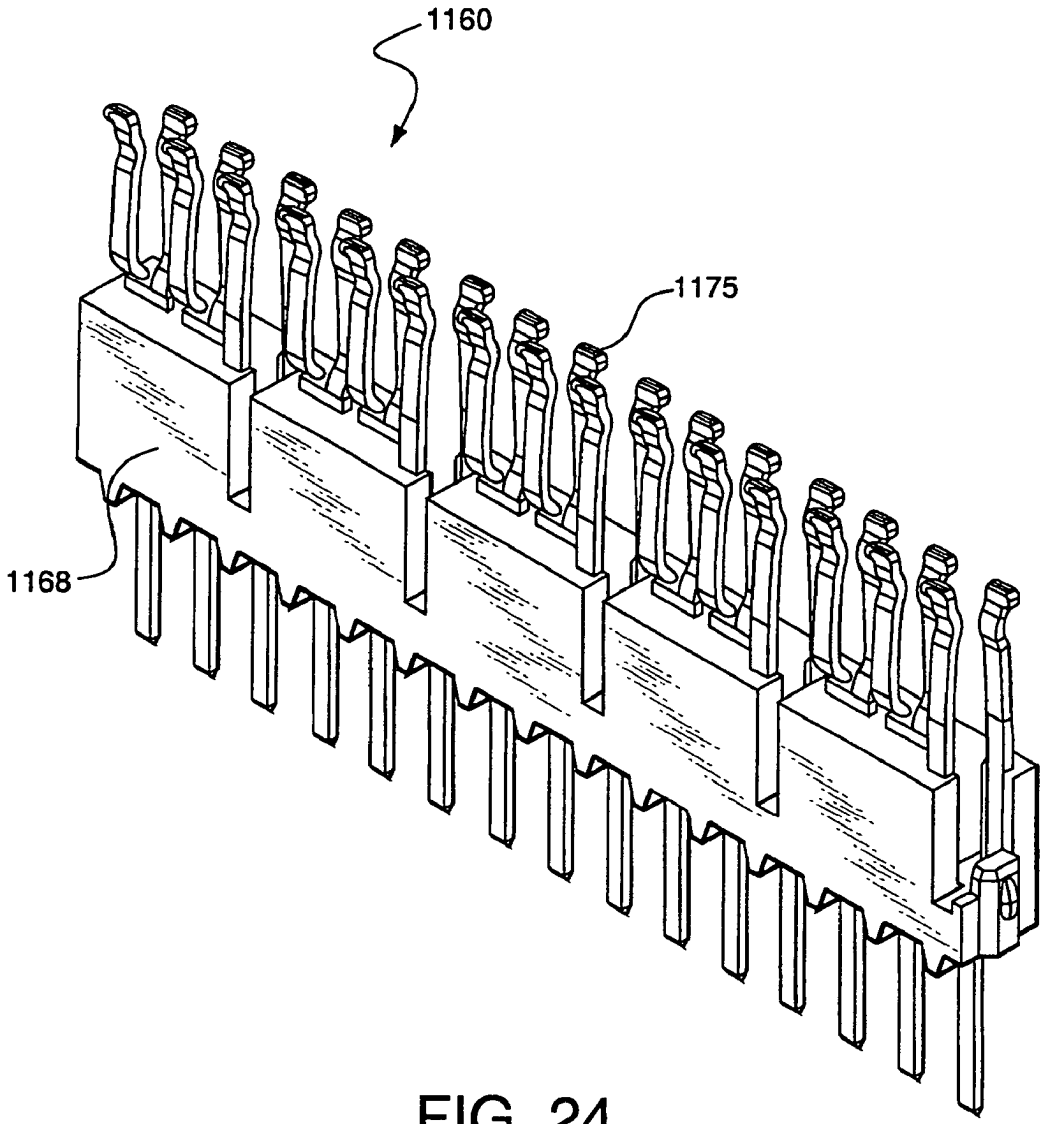


FIG. 24

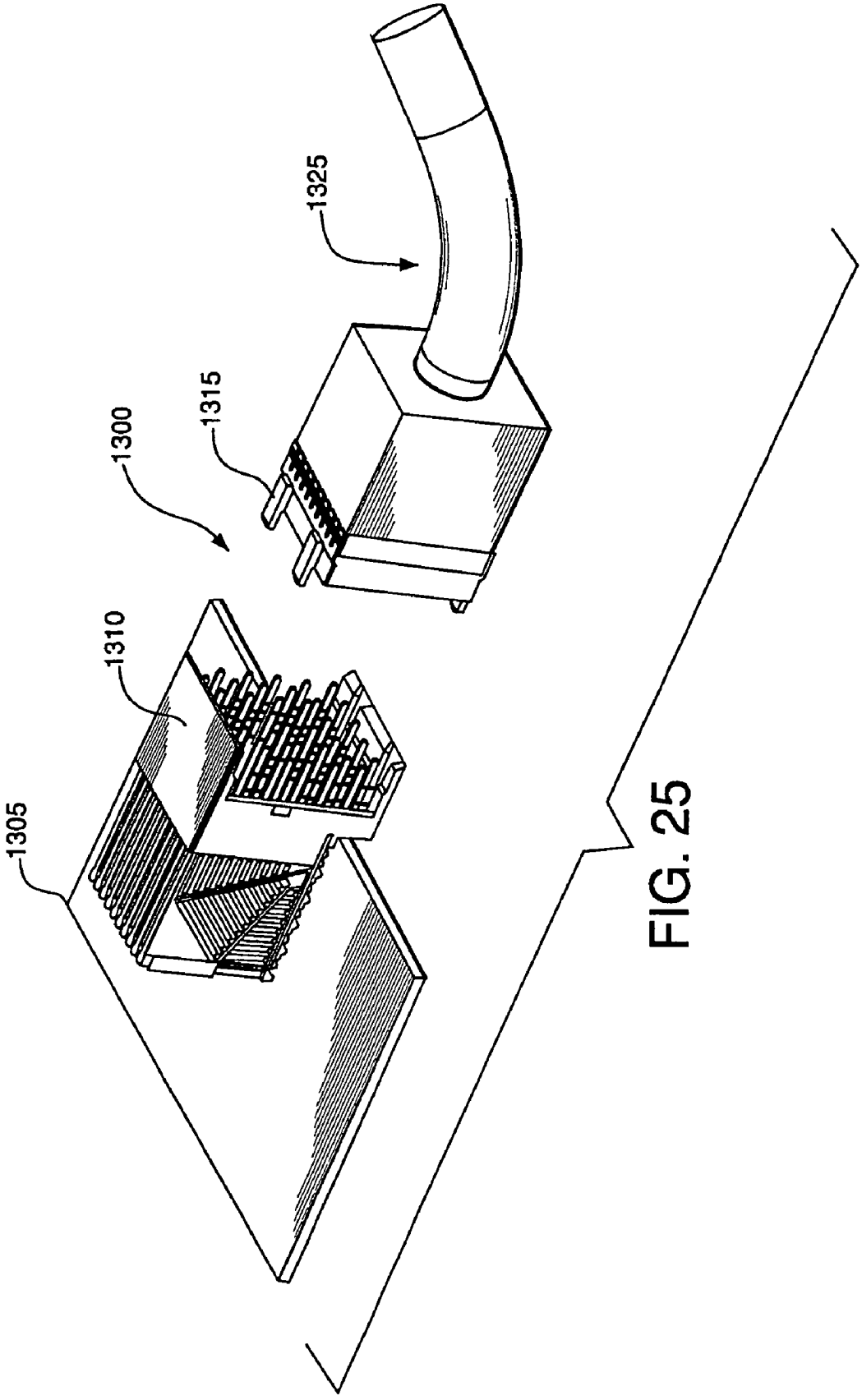


FIG. 25

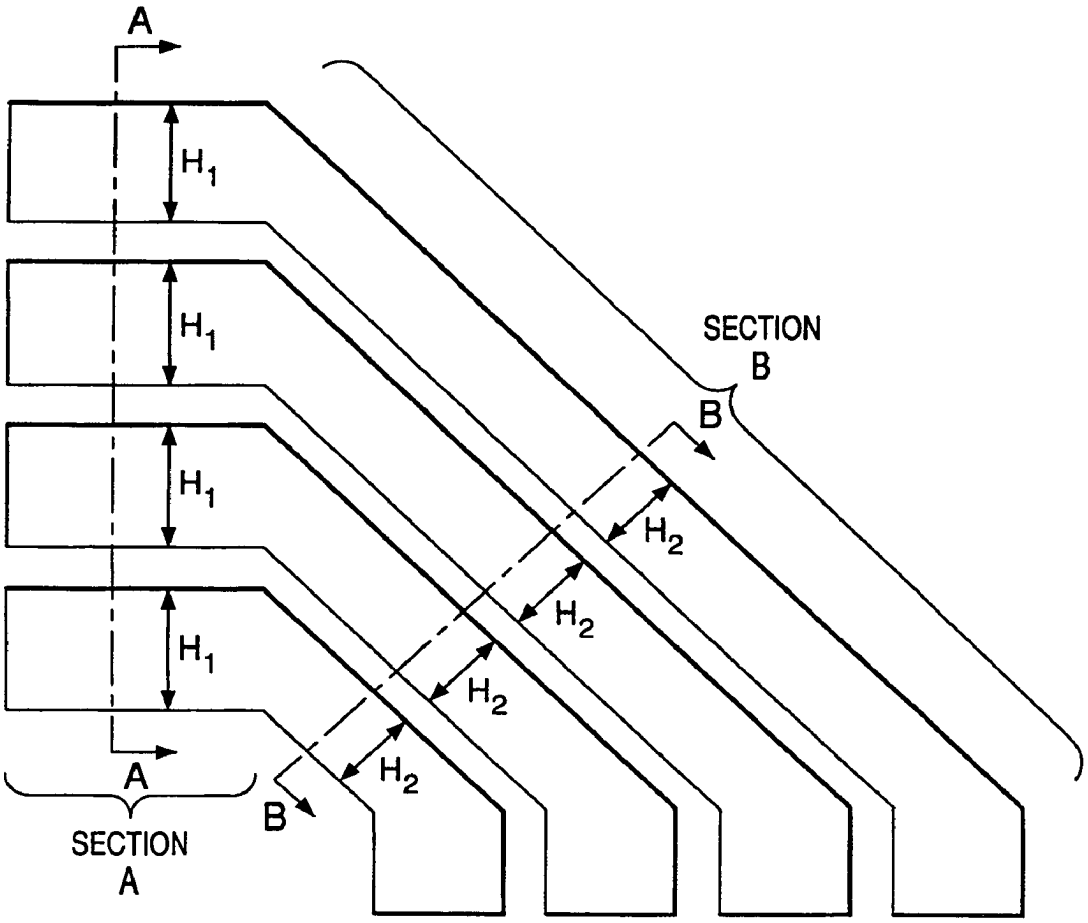
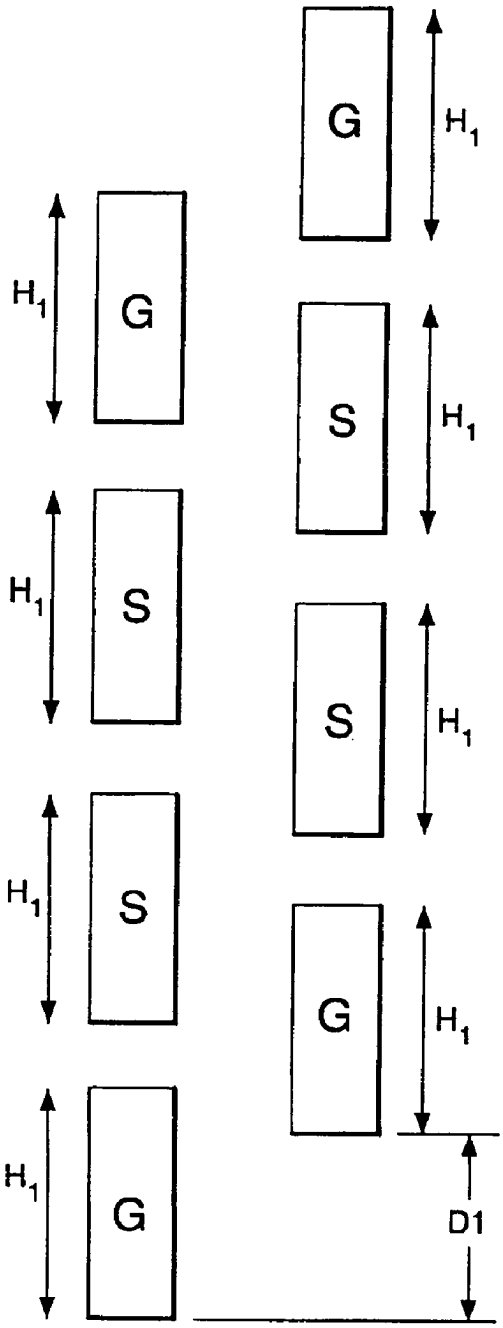
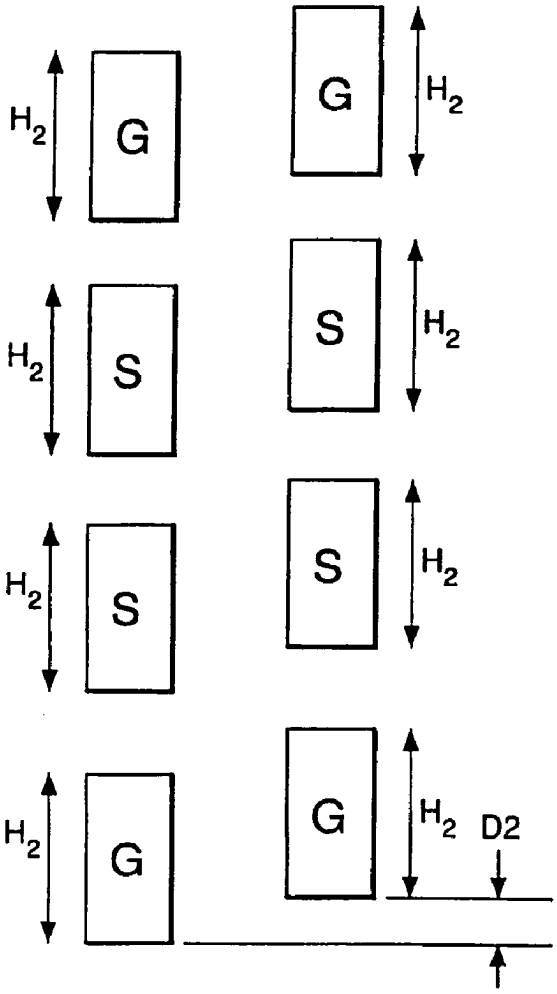


FIG. 26



Section A-A

FIG. 27



Section B-B

FIG. 28

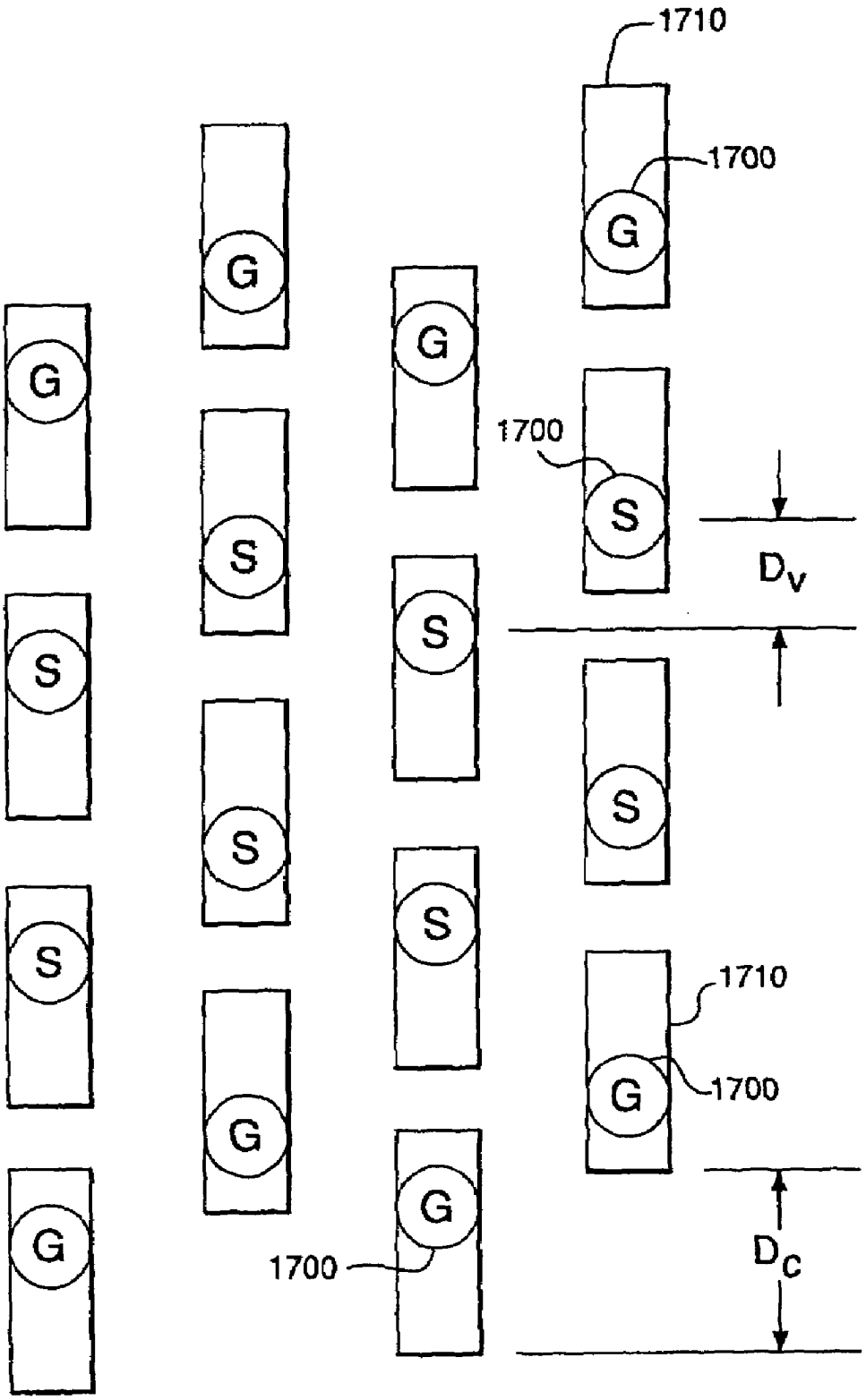


FIG. 29

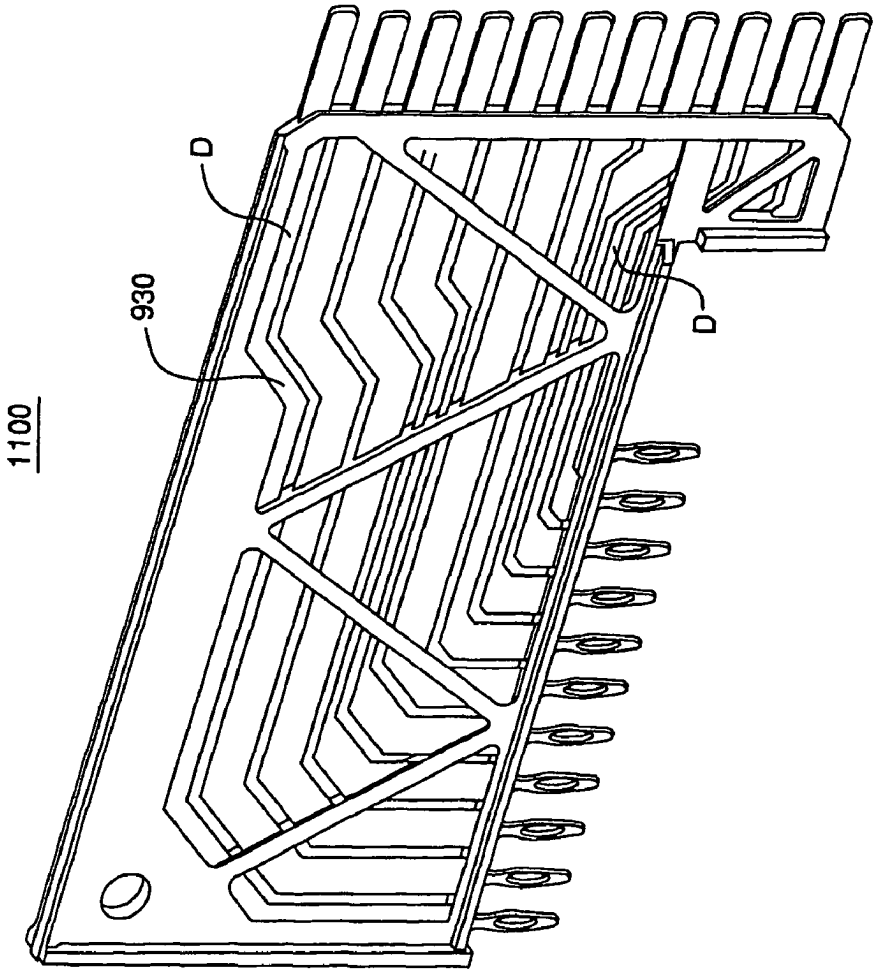


FIG. 30

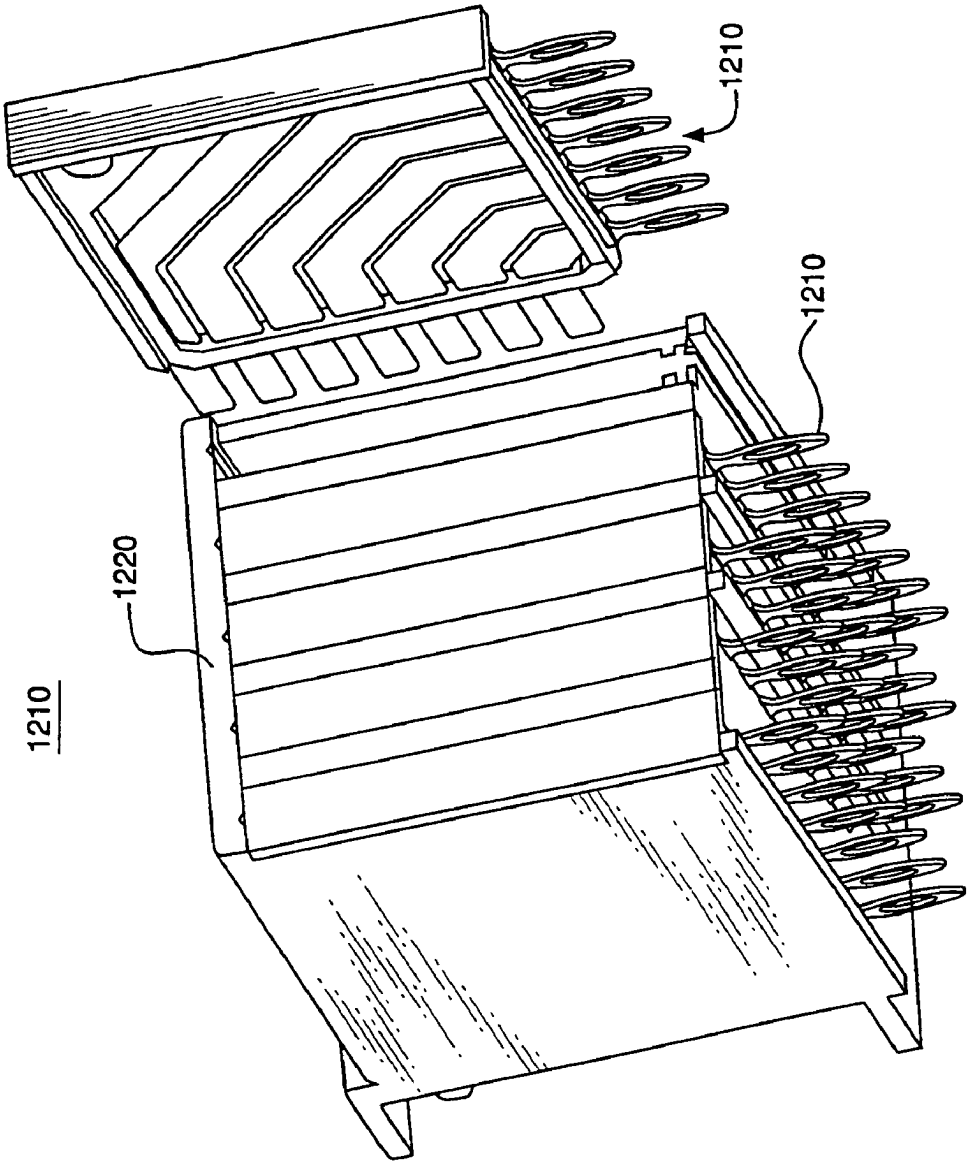


FIG. 31

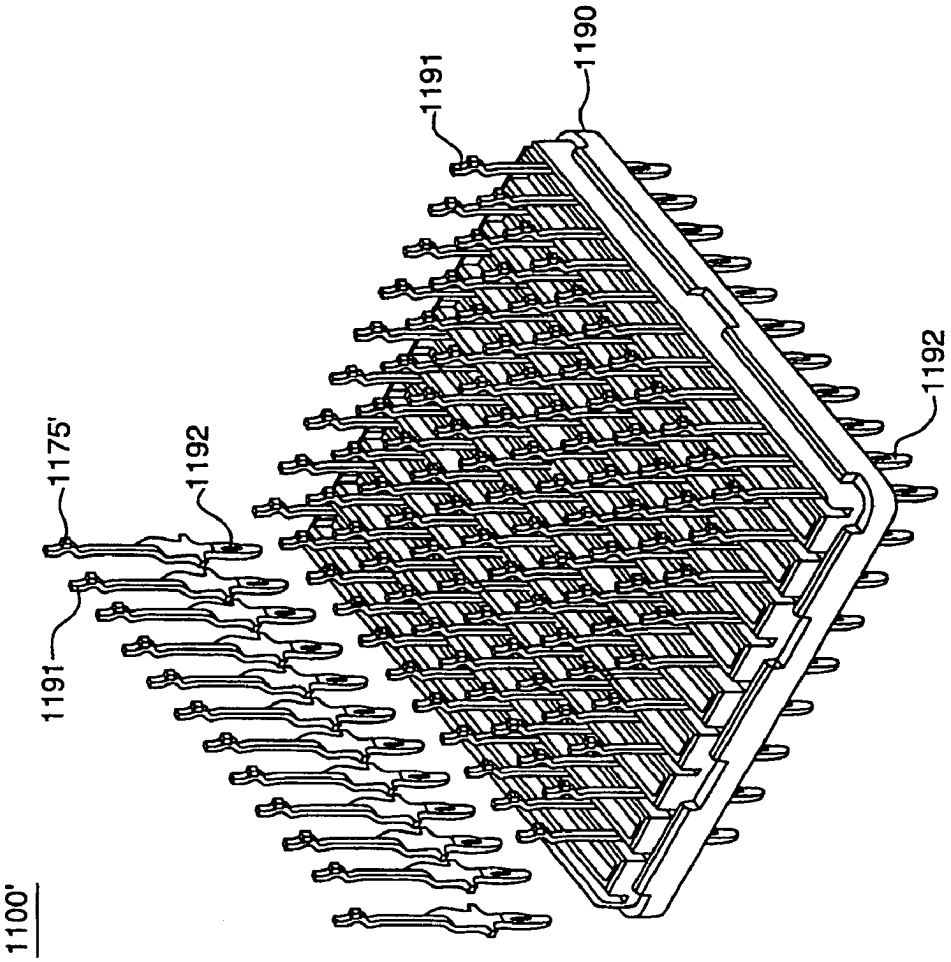


FIG. 32

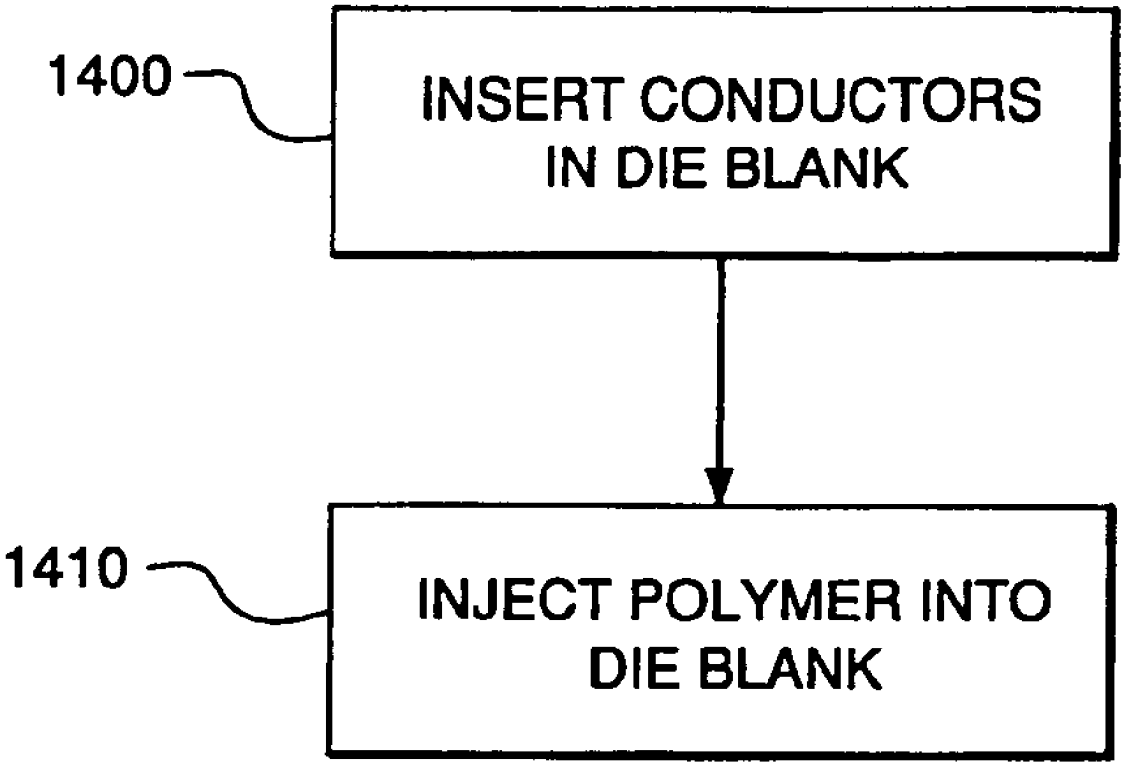

1400
INSERT CONDUCTORS IN DIE BLANK
1410
INJECT POLYMER INTO DIE BLANK

FIG. 33

CROSS TALK REDUCTION AND IMPEDANCE MATCHING FOR HIGH SPEED ELECTRICAL CONNECTORS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 10/294,966, filed Nov. 14, 2002, now U.S. Pat. No. 6,976,886 which is a continuation-in-part of U.S. patent application Ser. No. 09/990,794, filed Nov. 14, 2001, now U.S. Pat. No. 6,692,272, and of U.S. patent application Ser. No. 10/155,786, filed May 24, 2002, now U.S. Pat. No. 6,652,318. The contents of each of the above-referenced patents and patent applications is incorporated herein by reference.

FIELD OF THE INVENTION

Generally, the invention relates to the field of electrical connectors. More particularly, the invention relates to lightweight, low cost, high density electrical connectors that provide impedance controlled, high-speed, low interference communications, even in the absence of shields between the contacts, and that provide for a variety of other benefits not found in prior art connectors.

BACKGROUND OF THE INVENTION

Electrical connectors provide signal connections between electronic devices using signal contacts. Often, the signal contacts are so closely spaced that undesirable interference, or "cross talk," occurs between adjacent signal contacts. As used herein, the term "adjacent" refers to contacts (or rows or columns) that are next to one another. Cross talk occurs when one signal contact induces electrical interference in an adjacent signal contact due to intermingling electrical fields, thereby compromising signal integrity. With electronic device miniaturization and high speed, high signal integrity electronic communications becoming more prevalent, the reduction of cross talk becomes a significant factor in connector design.

One commonly used technique for reducing cross talk is to position separate electrical shields, in the form of metallic plates, for example, between adjacent signal contacts. The shields act to block cross talk between the signal contacts by blocking the intermingling of the contacts' electric fields. FIGS. **1**A and **1**B depict exemplary contact arrangements for electrical connectors that use shields to block cross talk.

FIG. **1**A depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along columns **101**–**106**. As shown, shields **112** can be positioned between contact columns **101**–**106**. A column **101**–**106** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same column. The shields **112** serve to block cross talk between differential signal pairs in adjacent columns.

FIG. **1**B depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along rows **111**–**116**. As shown, shields **122** can be positioned between rows **111**–**116**. A row **111**–**116** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same row. The shields **122** serve to block cross talk between differential signal pairs in adjacent rows.

Because of the demand for smaller, lower weight communications equipment, it is desirable that connectors be made smaller and lower in weight, while providing the same performance characteristics. Shields take up valuable space within the connector that could otherwise be used to provide additional signal contacts, and thus limit contact density (and, therefore, connector size). Additionally, manufacturing and inserting such shields substantially increase the overall costs associated with manufacturing such connectors. In some applications, shields are known to make up 40% or more of the cost of the connector. Another known disadvantage of shields is that they lower impedance. Thus, to make the impedance high enough in a high contact density connector, the contacts would need to be so small that they would not be robust enough for many applications.

The dielectrics that are typically used to insulate the contacts and retain them in position within the connector also add undesirable cost and weight.

Therefore, a need exists for a lightweight, high-speed electrical connector (i.e., one that operates above 1 Gb/s and typically in the range of about 10 Gb/s) that reduces the occurrence of cross talk without the need for separate shields, and provides for a variety of other benefits not found in prior art connectors.

BRIEF SUMMARY OF THE INVENTION

An electrical connector according to the invention may include a first signal contact positioned within a first linear array of electrical contacts and a second signal contact positioned within a second linear array of electrical contacts that is adjacent to the first linear array. Either of the signal contacts may be a single-ended signal conductor, or one of a differential signal pair. The connector may be devoid of shields between the signal contacts. The connector may be devoid of shields between the first linear array and the second linear array. The connector may be devoid of ground contacts adjacent to the signal contacts.

The connector may include a third signal contact or a ground contact disposed within the first linear array adjacent to the first signal contact. The first and third signal contacts may have a gap between them of between about 0.3 mm and 0.4 mm, and may be edge-coupled to one another. Such a connector may comprise a first column of electrical contacts comprising a first arrangement of differential signal pairs separated from one another by first ground contacts, a second column of electrical contacts comprising a second arrangement of differential signal pairs separated from one another by second ground contacts, wherein one differential signal pair in the second arrangement of differential signal pairs is a victim differential signal pair, and a third column of electrical contacts comprising a third arrangement of differential signal pairs separated from one another by third ground contacts. The second column may be adjacent to the first column, and the third column adjacent to the second column. The connector may be devoid of electrical shields between the first column and the second column, and between the second column and the third column. The contacts in the first column may be spaced apart from the contacts in the second column by a column-spacing distance of about 1.8–2.0 millimeters, and the contacts in the second column may be spaced apart from the contacts in the third column by the same column-spacing distance. Each of the differential signal pairs may define a gap distance between the electrical contacts that form the pair. The gap distance

relative to the column-spacing distance may be such that differential signals with rise times of 200 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case, multi-active cross talk on the victim differential signal pair.

The connector may be a high-speed connector, i.e., a connector that operates at signal speeds in a range of about one gigabit/sec to about ten gigabits/sec. Such a high-speed connector may comprise a first column of electrical contacts comprising a first arrangement of differential signal pairs each separated from one another by first ground contacts a second column of electrical contacts comprising a second arrangement of differential signal pairs each separated from one another by second ground contacts, wherein one differential signal pair in the second arrangement of differential signal pairs is a victim pair and a third column of electrical contacts comprising a third arrangement of differential signal pairs each separated from one another by third ground contacts. The second column may be adjacent to the first column, and the third column may be adjacent to the second column. The connector may be devoid of electrical shields between the first column and the second column, and between the second column and the third column. The first column, the second column, and the third column may be evenly spaced apart from one another by an equal column-spacing distance of about 1.8 to 2 millimeters. Each of the differential signal pairs may define a gap distance between electrical contacts that form each differential signal pair. The gap distance relative to the column-spacing distance may be such that differential signals with rise times of 40 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than an acceptable level of worst-case, multi-active cross talk on the victim pair.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further described in the detailed description that follows, by reference to the noted drawings by way of non-limiting illustrative embodiments of the invention, in which like reference numerals represent similar parts throughout the drawings, and wherein:

FIGS. **1**A and **1**B depict exemplary contact arrangements for electrical connectors that use shields to block cross talk;

FIG. **2**A is a schematic illustration of an electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry;

FIG. **2**B depicts equipotential regions within an arrangement of signal and ground contacts;

FIG. **3**A illustrates a conductor arrangement used to measure the effect of offset on multi-active cross talk;

FIG. **3**B is a graph illustrating the relationship between multi-active cross talk and offset between adjacent columns of terminals in accordance with one aspect of the invention;

FIG. **3**C depicts a contact arrangement for which cross talk was determined in a worst case scenario;

FIGS. **4**A–**4**C depict conductor arrangements in which signal pairs are arranged in columns;

FIG. **5** depicts a conductor arrangement in which signal pairs are arranged in rows;

FIG. **6** is a diagram showing an array of six columns of terminals arranged in accordance with one aspect of the invention;

FIG. **7** is a diagram showing an array of six columns arranged in accordance with another embodiment of the invention;

FIG. **8** is a perspective view of an illustrative right angle electrical connector, in accordance with the invention;

FIG. **9** is a side view of the right angle electrical connector of FIG. **8**;

FIG. **10** is a side view of a portion of the right angle electrical connector of FIG. **8** taken along line A—A;

FIG. **11** is a top view of a portion of the right angle electrical connector of FIG. **8** taken along line B—B;

FIG. **12** is a top cut-away view of conductors of the right angle electrical connector of FIG. **8** taken along line B—B;

FIG. **13**A is a side cut-away view of a portion of the right angle electrical connector of FIG. **8** taken along line A—A;

FIG. **13**B is a cross-sectional view taken along line C—C of FIG. **13**A;

FIG. **14** is a perspective view of illustrative conductors of a right angle electrical connector according to the invention;

FIG. **15** is a perspective view of another illustrative conductor of the right angle electrical connector of FIG. **8**;

FIG. **16**A is a perspective view of a backplane system having an exemplary right angle electrical connector;

FIG. **16**B is a simplified view of an alternative embodiment of a backplane system with a right angle electrical connector;

FIG. **16**C is a simplified view of a board-to-board system having a vertical connector;

FIG. **17** is a perspective view of the connector plug portion of the connector shown in FIG. **16**A;

FIG. **18** is a side view of the plug connector of FIG. **17**;

FIG. **19**A is a side view of a lead assembly of the plug connector of FIG. **17**;

FIG. **19**B depicts the lead assembly of FIG. **19** during mating;

FIG. **20** is a side view of two columns of terminals in accordance with one embodiment of the invention;

FIG. **21** is a front view of the terminals of FIG. **20**;

FIG. **22** is a perspective view of a receptacle in accordance with another embodiment of the invention;

FIG. **23** is a side view of the receptacle of FIG. **22**;

FIG. **24** is a perspective view of a single column of receptacle contacts;

FIG. **25** is a perspective view of a connector in accordance with another embodiment of the invention;

FIG. **26** is a side view of a column of right angle terminals in accordance with another aspect of the invention;

FIGS. **27** and **28** are front views of the right angle terminals of FIG. **26** taken along lines A—A and lines B—B respectively;

FIG. **29** illustrates the cross section of terminals as the terminals connect to vias on an electrical device in accordance with another aspect of the invention;

FIG. **30** is a perspective view of a portion of another illustrative right angle electrical connector, in accordance with the invention;

FIG. **31** is a perspective view of another illustrative right angle electrical connector, in accordance with the invention;

FIG. **32** is a perspective view of an alternative embodiment of a receptacle connector; and

FIG. **33** is a flow diagram of a method for making a connector in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

Certain terminology may be used in the following description for convenience only and should not be considered as limiting the invention in any way. For example, the terms "top," "bottom," "left," "right," "upper," and "lower"

designate directions in the figures to which reference is made. Likewise, the terms "inwardly" and "outwardly" designate directions toward and away from, respectively, the geometric center of the referenced object. The terminology includes the words above specifically mentioned, derivatives thereof, and words of similar import.

I-Shaped Geometry for Electrical Connectors—Theoretical Model

FIG. **2**A is a schematic illustration of an electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry. Such connectors are embodied in the assignee's "I-BEAM" technology, and are described and claimed in U.S. Pat. No. 5,741,144, entitled "Low Cross And Impedance Controlled Electric Connector," the disclosure of which is hereby incorporated herein by reference in its entirety. Low cross talk and controlled impedance have been found to result from the use of this geometry.

The originally contemplated I-shaped transmission line geometry is shown in FIG. **2**A. As shown, the conductive element can be perpendicularly interposed between two parallel dielectric and ground plane elements. The description of this transmission line geometry as I-shaped comes from the vertical arrangement of the signal conductor shown generally at numeral **10** between the two horizontal dielectric layers **12** and **14** having a dielectric constant ϵ and ground planes **13** and **15** symmetrically placed at the top and bottom edges of the conductor. The sides **20** and **22** of the conductor are open to the air **24** having an air dielectric constant ϵ_0. In a connector application, the conductor could include two sections, **26** and **28**, that abut end-to-end or face-to-face. The thickness, t_1 and t_2 of the dielectric layers **12** and **14**, to first order, controls the characteristic impedance of the transmission line and the ratio of the overall height h to dielectric width w_d controls the electric and magnetic field penetration to an adjacent contact. Original experimentation led to the conclusion that the ratio h/w_d needed to minimize interference beyond A and B would be approximately unity (as illustrated in FIG. **2**A).

The lines **30**, **32**, **34**, **36** and **38** in FIG. **2**A are equipotentials of voltage in the air-dielectric space. Taking an equipotential line close to one of the ground planes and following it out towards the boundaries A and B, it will be seen that both boundary A or boundary B are very close to the ground potential. This means that virtual ground surfaces exist at each of boundary A and boundary B. Therefore, if two or more I-shaped modules are placed side-by-side, a virtual ground surface exists between the modules and there will be little to no intermingling of the modules' fields. In general, the conductor width w_c and dielectric thicknesses t_1, t_2 should be small compared to the dielectric width w_d or module pitch (i.e., distance between adjacent modules).

Given the mechanical constraints on a practical connector design, it was found in actuality that the proportioning of the signal conductor (blade/beam contact) width and dielectric thicknesses could deviate somewhat from the preferred ratios and some minimal interference might exist between adjacent signal conductors. However, designs using the above-described I-shaped geometry tend to have lower cross talk than other conventional designs.

Exemplary Factors Affecting Cross Talk Between Adjacent Contacts

In accordance with the invention, the basic principles described above were further analyzed and expanded upon and can be employed to determine how to even further limit cross talk between adjacent signal contacts, even in the absence of shields between the contacts, by determining an appropriate arrangement and geometry of the signal and ground contacts. FIG. **2**B includes a contour plot of voltage in the neighborhood of an active column-based differential signal pair S+, S− in a contact arrangement of signal contacts S and ground contacts G according to the invention. As shown, contour lines **42** are closest to zero volts, contour lines **44** are closest to −1 volt, and contour lines **46** are closest to +1 volt. It has been observed that, although the voltage does not necessarily go to zero at the "quiet" differential signal pairs that are nearest to the active pair, the interference with the quiet pairs is near zero. That is, the voltage impinging on the positive-going quiet differential pair signal contact is about the same as the voltage impinging on the negative-going quiet differential pair signal contact. Consequently, the noise on the quiet pair, which is the difference in voltage between the positive- and negative-going signals, is close to zero.

Thus, as shown in FIG. **2**B, the signal contacts S and ground contacts G can be scaled and positioned relative to one another such that a differential signal in a first differential signal pair produces a high field H in the gap between the contacts that form the signal pair and a low (i.e., close to ground potential) field L (close to ground potential) near an adjacent signal pair. Consequently, cross talk between adjacent signal contacts can be limited to acceptable levels for the particular application. In such connectors, the level of cross talk between adjacent signal contacts can be limited to the point that the need for (and cost of) shields between adjacent contacts is unnecessary, even in high speed, high signal integrity applications.

Through further analysis of the above-described I-shaped model, it has been found that the unity ratio of height to width is not as critical as it first seemed. It has also been found that a number of factors can affect the level of cross talk between adjacent signal contacts. A number of such factors are described in detail below, though it is anticipated that there may be others. Additionally, though it is preferred that all of these factors be considered, it should be understood that each factor may, alone, sufficiently limit cross talk for a particular application. Any or all of the following factors may be considered in determining a suitable contact arrangement for a particular connector design:

a) Less cross talk has been found to occur where adjacent contacts are edge-coupled (i.e., where the edge of one contact is adjacent to the edge of an adjacent contact) than where adjacent contacts are broad side coupled (i.e., where the broad side of one contact is adjacent to the broad side of an adjacent contact) or where the edge of one contact is adjacent to the broad side of an adjacent contact. The tighter the edge coupling, the less the coupled signal pair's electrical field will extend towards an adjacent pair and the less the towards the unity height-to-width ratio of the original I-shaped theoretical model a connector application will have to approach. Edge coupling also allows for smaller gap widths between adjacent connectors, and thus facilitates the achievement of desirable impedance levels in high contact density connectors without the need for contacts that are too small to perform adequately. For example, it has been found than a gap of about 0.3–0.4 mm is adequate to provide an impedance of about 100 ohms where the contacts are edge coupled, while a gap of about 1 mm is necessary where the same contacts are broad side coupled to achieve the same impedance. Edge coupling also facilitates changing contact width, and therefore gap width, as the contact extends through dielectric regions, contact regions, etc.;

b) It has also been found that cross talk can be effectively reduced by varying the "aspect ratio," i.e., the ratio of column pitch (i.e., the distance between adjacent columns) to the gap between adjacent contacts in a given column;

c) The "staggering" of adjacent columns relative to one another can also reduce the level of cross talk. That is, cross talk can be effectively limited where the signal contacts in a first column are offset relative to adjacent signal contacts in an adjacent column. The amount of offset may be, for example, a full row pitch (i.e., distance between adjacent rows), half a row pitch, or any other distance that results in acceptably low levels of cross talk for a particular connector design. It has been found that the optimal offset depends on a number of factors, such as column pitch, row pitch, the shape of the terminals, and the dielectric constant(s) of the insulating material(s) around the terminals, for example. It has also been found that the optimal offset is not necessarily "on pitch," as was often thought. That is, the optimal offset may be anywhere along a continuum, and is not limited to whole fractions of a row pitch (e.g., full or half row pitches).

FIG. **3**A illustrates a contact arrangement that has been used to measure the effect of offset between adjacent columns on cross talk. Fast (e.g., 40 ps) rise-time differential signals were applied to each of Active Pair **1** and Active Pair **2**. Near-end crosstalk Nxt**1** and Nxt**2** were determined at Quiet Pair, to which no signal was applied, as the offset d between adjacent columns was varied from 0 to 5.0 mm. Near-end cross talk occurs when noise is induced on the quiet pair from the current carrying contacts in an active pair.

As shown in the graph of FIG. **3**B, the incidence of multi-active cross talk (dark line in FIG. **3**B) is minimized at offsets of about 1.3 mm and about 3.65 mm. In this experiment, multi-active cross talk was considered to be the sum of the absolute values of cross talk from each of Active Pair **1** (dashed line in FIG. **3**B) and Active Pair **2** (thin solid line in FIG. **3**B). Thus, it has been shown that adjacent columns can be variably offset relative to one another until an optimum level of cross talk between adjacent pairs (about 1.3 mm, in this example);

d) Through the addition of outer grounds, i.e., the placement of ground contacts at alternating ends of adjacent contact columns, both near-end cross talk ("NEXT") and far-end cross talk ("FEXT") can be further reduced;

e) It has also been found that scaling the contacts (i.e., reducing the absolute dimensions of the contacts while preserving their proportional and geometric relationship) provides for increased contact density (i.e., the number of contacts per linear inch) without adversely affecting the electrical characteristics of the connector.

By considering any or all of these factors, a connector can be designed that delivers high-performance (i.e., low incidence of cross talk), high-speed (e.g., greater than 1 Gb/s and typically about 10 Gb/s) communications even in the absence of shields between adjacent contacts. It should also be understood that such connectors and techniques, which are capable of providing such high speed communications, are also useful at lower speeds. Connectors according to the invention have been shown, in worst case testing scenarios, to have near-end cross talk of less than about 3% and far-end cross talk of less than about 4%, at 40 picosecond rise time, with 63.5 mated signal pairs per linear inch. Such connectors can have insertion losses of less than about 0.7 dB at 5 GHz, and impedance match of about 100±8 ohms measured at a 40 picosecond rise time.

FIG. **3**C depicts a contact arrangement for which cross talk was determined in a worst case scenario. Cross talk from each of six attacking pairs S**1**, S**2**, S**3**, S**4**, S**5**, and S**6** was determined at a "victim" pair V. Attacking pairs S**1**, S**2**, S**3**, S**4**, S**5**, and S**6** are six of the eight nearest neighboring pairs to signal pair V. It has been determined that the additional affects on cross talk at victim pair V from attacking pairs S**7** and S**8** is negligible. The combined cross talk from the six nearest neighbor attacking pairs has been determined by summing the absolute values of the peak cross talk from each of the pairs, which assumes that each pair is fairing at the highest level all at the same time. Thus, it should be understood that this is a worst case scenario, and that, in practice, much better results should be achieved.

Exemplary Contact Arrangements According to the Invention

FIG. **4**A depicts a connector **100** according to the invention having column-based differential signal pairs (i.e., in which differential signal pairs are arranged into columns). (As used herein, a "column" refers to the direction along which the contacts are edge coupled. A "row" is perpendicular to a column.) As shown, each column **401**–**406** comprises, in order from top to bottom, a first differential signal pair, a first ground conductor, a second differential signal pair, and a second ground conductor. As can be seen, first column **401** comprises, in order from top to bottom, a first differential signal pair comprising signal conductors S**1**+ and S**1**−, a first ground conductor G, a second differential signal pair comprising signal conductors S**7**+ and S**7**−, and a second ground conductor G. Each of rows **413** and **416** comprises a plurality of ground conductors G. Rows **411** and **412** together comprise six differential signal pairs, and rows **514** and **515** together comprise another six differential signal pairs. The rows **413** and **416** of ground conductors limit cross talk between the signal pairs in rows **411**–**412** and the signal pairs in rows **414**–**415**. In the embodiment shown in FIG. **4**A, arrangement of 36 contacts into columns can provide twelve differential signal pairs. Because the connector is devoid of shields, the contacts can be made relatively larger (compared to those in a connector having shields). Therefore, less connector space is needed to achieve the desired impedance.

FIGS. **4**B and **4**C depict connectors according to the invention that include outer grounds. As shown in FIG. **4**B, a ground contact G can be placed at each end of each column. As shown in FIG. **4**C, a ground contact G can be placed at alternating ends of adjacent columns. It has been found that the placement of a ground contact G at alternating ends of adjacent columns results in a 35% reduction in NEXT and a 65% reduction in FEXT as compared to a connector having a contact arrangement that is otherwise the same, but which has no such outer grounds. It has also been found that basically the same results can be achieved through the placement of ground contacts at both ends of every contact column, as shown in FIG. **4**B. Consequently, it is preferred to place outer grounds at alternating ends of adjacent columns in order to increase contact density (relative to a connector in which outer grounds are placed at both ends of every column) without increasing the level of cross talk.

Alternatively, as shown in FIG. **5**, differential signal pairs may be arranged into rows. As shown in FIG. **5**, each row **511**–**516** comprises a repeating sequence of two ground conductors and a differential signal pair. First row **511** comprises, in order from left to right, two ground conductors G, a differential signal pair S**1**+, S**1**−, and two ground conductors G. Row **512** comprises in order from left to right, a differential signal pair S**2**+, S**2**−, two ground conductors G,

and a differential signal pair S3+, S3−. The ground conductors block cross talk between adjacent signal pairs. In the embodiment shown in FIG. **5**, arrangement of 36 contacts into rows provides only nine differential signal pairs.

By comparison of the arrangement shown in FIG. **4**A with the arrangement shown in FIG. **5**, it can be understood that a column arrangement of differential signal pairs results in a higher density of signal contacts than does a row arrangement. However, for right angle connectors arranged into columns, contacts within a differential signal pair have different lengths, and therefore, such differential signal pairs may have intra-pair skew. Similarly, arrangement of signal pairs into either rows or columns may result in inter-pair skew because of the different conductor lengths of different differential signal pairs. Thus, it should be understood that, although arrangement of signal pairs into columns results in a higher contact density, arrangement of the signal pairs into columns or rows can be chosen for the particular application.

Regardless of whether the signal pairs are arranged into rows or columns, each differential signal pair has a differential impedance Z_0 between the positive conductor Sx+ and negative conductor Sx− of the differential signal pair. Differential impedance is defined as the impedance existing between two signal conductors of the same differential signal pair, at a particular point along the length of the differential signal pair. As is well known, it is desirable to control the differential impedance Z_0 to match the impedance of the electrical device(s) to which the connector is connected. Matching the differential impedance Z_0 to the impedance of electrical device minimizes signal reflection and/or system resonance that can limit overall system bandwidth. Furthermore, it is desirable to control the differential impedance Z_0 such that it is substantially constant along the length of the differential signal pair, i.e., such that each differential signal pair has a substantially consistent differential impedance profile.

The differential impedance profile can be controlled by the positioning of the signal and ground conductors. Specifically, differential impedance is determined by the proximity of an edge of signal conductor to an adjacent ground and by the gap between edges of signal conductors within a differential signal pair.

As shown in FIG. **4**A, the differential signal pair comprising signal conductors S**6**+ and S**6**− is located adjacent to one ground conductor G in row **413**. The differential signal pair comprising signal conductors S**12**+ and S**12**− is located adjacent to two ground conductors G, one in row **413** and one in row **416**. Conventional connectors include two ground conductors adjacent to each differential signal pair to minimize impedance matching problems. Removing one of the ground conductors typically leads to impedance mismatches that reduce communications speed. However, the lack of one adjacent ground conductor can be compensated for by reducing the gap between the differential signal pair conductors with only one adjacent ground conductor. For example, as shown in FIG. **4**A, signal conductors S**6**+ and S**6**− can be located a distance d_1 apart from each other and signal conductors S**12**+ and S**12**− can be located a different distance d_2 apart from each other. The distances may be controlled by making the widths of signal conductors S**6**+ and S**6**− wider than the widths of signal conductors S**12**+ and S**12**− (where conductor width is measured along the direction of the column).

For single ended signaling, single ended impedance can also be controlled by positioning of the signal and ground conductors. Specifically, single ended impedance is determined by the gap between a signal conductor and an adjacent ground. Single ended impedance is defined as the impedance existing between a signal conductor and ground, at a particular point along the length of a single ended signal conductor.

To maintain acceptable differential impedance control for high bandwidth systems, it is desirable to control the gap between contacts to within a few thousandths of an inch. Gap variations beyond a few thousandths of an inch may cause unacceptable variation in the impedance profile; however, the acceptable variation is dependent on the speed desired, the error rate acceptable, and other design factors.

FIG. **6** shows an array of differential signal pairs and ground contacts in which each column of terminals is offset from each adjacent column. The offset is measured from an edge of a terminal to the same edge of the corresponding terminal in the adjacent column. The aspect ratio of column pitch to gap width, as shown in FIG. **6**, is P/X. It has been found that an aspect ratio of about 5 (i.e., 2 mm column pitch; 0.4 mm gap width) is adequate to sufficiently limit cross talk where the columns are also staggered. Where the columns are not staggered, an aspect ratio of about 8–10 is desirable.

As described above, by offsetting the columns, the level of multi-active cross talk occurring in any particular terminal can be limited to a level that is acceptable for the particular connector application. As shown in FIG. **6**, each column is offset from the adjacent column, in the direction along the columns, by a distance d. Specifically, column **601** is offset from column **602** by an offset distance d, column **602** is offset from column **603** by a distance d, and so forth. Since each column is offset from the adjacent column, each terminal is offset from an adjacent terminal in an adjacent column. For example, signal contact **680** in differential pair DP**3** is offset from signal contact **681** in differential pair DP**4** by a distance d as shown.

FIG. **7** illustrates another configuration of differential pairs wherein each column of terminals is offset relative to adjacent columns. For example, as shown, differential pair DP**1** in column **701** is offset from differential pair DP**2** in the adjacent column **702** by a distance d. In this embodiment, however, the array of terminals does not include ground contacts separating each differential pair. Rather, the differential pairs within each column are separated from each other by a distance greater than the distance separating one terminal in a differential pair from the second terminal in the same differential pair. For example, where the distance between terminals within each differential pair is Y, the distance separating differential pairs can be Y+X, where Y+X/Y >>1. It has been found that such spacing also serves to reduce cross talk.

Exemplary Connector Systems According to the Invention

FIG. **8** is a perspective view of a right angle electrical connector according to the invention that is directed to a high speed electrical connector wherein signal conductors of a differential signal pair have a substantially constant differential impedance along the length of the differential signal pair. As shown in FIG. **8**, a connector **800** comprises a first section **801** and a second section **802**. First section **801** is electrically connected to a first electrical device **810** and second section **802** is electrically connected to a second electrical device **812**. Such connections may be SMT, PIP, solder ball grid array, press fit, or other such connections. Typically, such connections are conventional connections having conventional connection spacing between connection pins; however, such connections may have other spacing between connection pins. First section **801** and second

section **802** can be electrically connected together, thereby electrically connecting first electrical device **810** to second electrical device **812**.

As can be seen, first section **801** comprises a plurality of modules **805**. Each module **805** comprises a column of conductors **830**. As shown, first section **801** comprises six modules **805** and each module **805** comprises six conductors **830**; however, any number of modules **805** and conductors **830** may be used. Second section **802** comprises a plurality of modules **806**. Each module **806** comprises a column of conductors **840**. As shown, second section **802** comprises six modules **806** and each module **806** comprises six conductors **840**; however, any number of modules **806** and conductors **840** may be used.

FIG. **9** is a side view of connector **800**. As shown in FIG. **9**, each module **805** comprises a plurality of conductors **830** secured in a frame **850**. Each conductor **830** comprises a connection pin **832** extending from frame **850** for connection to first electrical device **810**, a blade **836** extending from frame **850** for connection to second section **802**, and a conductor segment **834** connecting connection pin **832** to blade **836**.

Each module **806** comprises a plurality of conductors **840** secured in frame **852**. Each conductor **840** comprises a contact interface **841** and a connection pin **842**. Each contact interface **841** extends from frame **852** for connection to a blade **836** of first section **801**. Each contact interface **840** is also electrically connected to a connection pin **842** that extends from frame **852** for electrical connection to second electrical device **812**.

Each module **805** comprises a first hole **856** and a second hole **857** for alignment with an adjacent module **805**. Thus, multiple columns of conductors **830** may be aligned. Each module **806** comprises a first hole **847** and a second hole **848** for alignment with an adjacent module **806**. Thus, multiple columns of conductors **840** may be aligned.

Module **805** of connector **800** is shown as a right angle module. That is, a set of first connection pins **832** is positioned on a first plane (e.g., coplanar with first electrical device **810**) and a set of second connection pins **842** is positioned on a second plane (e.g., coplanar with second electrical device **812**) perpendicular to the first plane. To connect the first plane to the second plane, each conductor **830** turns a total of about ninety degrees (a right angle) to connect between electrical devices **810** and **812**.

To simplify conductor placement, conductors **830** can have a rectangular cross section; however, conductors **830** may be any shape. In this embodiment, conductors **830** have a high ratio of width to thickness to facilitate manufacturing. The particular ratio of width to thickness may be selected based on various design parameters including the desired communication speed, connection pin layout, and the like.

FIG. **10** is a side view of two modules of connector **800** taken along line A—A and FIG. **11** is a top view of two modules of connector **800** taken along line B—B. As can be seen, each blade **836** is positioned between two single beam contacts **849** of contact interface **841**, thereby providing electrical connection between first section **801** and second section **802** and described in more detail below. Connection pins **832** are positioned proximate to the centerline of module **805** such that connection pins **832** may be mated to a device having conventional connection spacing. Connection pins **842** are positioned proximate to the centerline of module **806** such that connection pins **842** may be mated to a device having conventional connection spacing. Connection pins, however, may be positioned at an offset from the centerline of module **806** if such connection spacing is supported by the mating device. Further, while connection pins are illustrated in the Figures, other connection techniques are contemplated such as, for example, solder balls and the like.

Returning now to illustrative connector **800** of FIG. **8** to discuss the layout of connection pins and conductors, first section **801** of connector **800** comprises six columns and six rows of conductors **830**. Conductors **830** may be either signal conductors S or ground conductors G. Typically, each signal conductor S is employed as either a positive conductor or a negative conductor of a differential signal pair; however, a signal conductor may be employed as a conductor for single ended signaling. In addition, such conductors **830** may be arranged in either columns or rows.

In addition to conductor placement, differential impedance and insertion losses are also affected by the dielectric properties of material proximate to the conductors. Generally, it is desirable to have materials having very low dielectric constants adjacent and in contact with as much as the conductors as possible. Air is the most desirable dielectric because it allows for a lightweight connector and has the best dielectric properties. While frame **850** and frame **852** may comprise a polymer, a plastic, or the like to secure conductors **830** and **840** so that desired gap tolerances may be maintained, the amount of plastic used is minimized. Therefore, the rest of connector comprises an air dielectric and conductors **830** and **840** are positioned both in air and only minimally in a second material (e.g., a polymer) having a second dielectric property. Therefore, to provide a substantially constant differential impedance profile, in the second material, the spacing between conductors of a differential signal pair may vary.

As shown, the conductors can be exposed primarily to air rather than being encased in plastic. The use of air rather than plastic as a dielectric provides a number of benefits. For example, the use of air enables the connector to be formed from much less plastic than conventional connectors. Thus, a connector according to the invention can be made lower in weight than convention connectors that use plastic as the dielectric. Air also allows for smaller gaps between contacts and thereby provides for better impedance and cross talk control with relatively larger contacts, reduces cross-talk, provides less dielectric loss, increases signal speed (i.e., less propagation delay).

Through the use of air as the primary dielectric, a lightweight, low-impedance, low cross talk connector can be provided that is suitable for use as a ball grid assembly ("BGA") right-angle connector. Typically, a right angle connector is "off-balance, i.e., disproportionately heavy in the mating area. Consequently, the connector tends to "tilt" in the direction of the mating area. Because the solder balls of the BGA, while molten, can only support a certain mass, prior art connectors typically are unable to include additional mass to balance the connector. Through the use of air, rather than plastic, as the dielectric, the mass of the connector can be reduced. Consequently, additional mass can be added to balance the connector without causing the molten solder balls to collapse.

FIG. **12** illustrates the change in spacing between conductors in rows as conductors pass from being surrounded by air to being surrounded by frame **850**. As shown in FIG. **12**, at connection pin **832** the distance between conductor S+ and S− is δ**1**. Distance δ**1** may be selected to mate with conventional connector spacing on first electrical device **810** or may be selected to optimize the differential impedance profile. As shown, distance δ**1** is selected to mate with a conventional connector and is disposed proximate to the

centerline of module **805**. As conductors S+ and S− travel from connection pins **832** through frame **850**, portions **833** of conductors S+, S− jog towards each other, culminating in a separation distance δ**2** in air region **860**. Distance δ**2** is selected to give the desired differential impedance between conductor S+ and S−, given other parameters, such as proximity to a ground conductor G. For example, given a spacing δ**1**, spacing δ**2** may be chosen to provide for a constant differential impedance Z along the length of the conductor S+, S−. The desired differential impedance Z_0 depends on the system impedance (e.g., of first electrical device **810**), and may be 100 ohms or some other value. Typically, a tolerance of about 5 percent is desired; however, 10 percent may be acceptable for some applications. It is this range of 10% or less that is considered substantially constant differential impedance.

As shown in FIG. **13**A, conductors S+ and S− are disposed from air region **860** towards blade **836** and portions **835** jog outward with respect to each other within frame **850** such that blades **836** are separated by a distance δ**3** upon exiting frame **850**. Blades **836** are received in contact interfaces **841**, thereby providing electrical connection between first section **801** and second section **802**. As contact interfaces **841** travel from air region **860** towards frame **852**, contact interfaces **841** jog outwardly with respect to each other, culminating in connection pins **842** separated by a distance of δ**4**. As shown, connection pins **842** are disposed proximate to the centerline of frame **852** to mate with conventional connector spacing.

FIG. **14** is a perspective view of conductors **830**. As can be seen, within frame **850**, conductors **830** jog, either inwardly or outwardly to maintain a substantially constant differential impedance profile along the conductive path.

FIG. **15** is a perspective view of conductor **840** that includes two single beam contacts **849**, one beam contact **849** on each side of blade **836**. This design may provide reduced cross talk performance, because each single beam contact **849** is further away from its adjacent contact. Also, this design may provide increased contact reliability, because it is a "true" dual contact. This design may also reduce the tight tolerance requirements for the positioning of the contacts and forming of the contacts.

As can be seen, within frame **852**, conductor **840** jogs, either inward or outward to maintain a substantially constant differential impedance profile and to mate with connectors on second electrical device **812**. For arrangement into columns, conductors **830** and **840** are positioned along a centerline of frames **850**, **852**, respectively.

FIG. **13**B is a cross-sectional view taken along line C—C of FIG. **13**A. As shown in FIG. **13**B, terminal blades **836** are received in contact interfaces **841** such that beam contacts **839** engage respective sides of blades **836**. Preferably, the beam contacts **839** are sized and shaped to provide contact between the blades **836** and the contact interfaces **841** over a combined surface area that is sufficient to maintain the electrical characteristics of the connector during mating and unmating of the connector.

As shown in FIG. **13**B, the contact design allows the edge-coupled aspect ratio to be maintained in the mating region. That is, the aspect ratio of column pitch to gap width chosen to limit cross talk in the connector, exists in the contact region as well, and thereby limits cross talk in the mating region. Also, because the cross-section of the unmated blade contact is nearly the same as the combined cross-section of the mated contacts, the impedance profile can be maintained even if the connector is partially unmated. This occurs, at least in part, because the combined cross-section of the mated contacts includes no more than one or two thickness of metal (the thicknesses of the blade and the contact interface), rather than three thicknesses as would be typical in prior art connectors (see FIG. **13**B, for example). Unplugging a connector such as shown in FIG. **13**B results in a significant change in cross-section, and therefore, a significant change in impedance (which causes significant degradation of electrical performance if the connector is not properly and completely mated). Because the contact cross-section does not change dramatically as the connector is unmated, the connector (as shown in FIG. **13**A) can provide nearly the same electrical characteristics when partially unmated (i.e., unmated by about 1–2 mm) as it does when fully mated.

FIG. **16**A is a perspective view of a backplane system having an exemplary right angle electrical connector in accordance with an embodiment of the invention. As shown in FIG. **16**A, connector **900** comprises a plug **902** and receptacle **1100**.

Plug **902** comprises housing **905** and a plurality of lead assemblies **908**. The housing **905** is configured to contain and align the plurality of lead assemblies **908** such that an electrical connection suitable for signal communication is made between a first electrical device **910** and a second electrical device **912** via receptacle **1100**. In one embodiment of the invention, electrical device **910** is a backplane and electrical device **912** is a daughtercard. Electrical devices **910** and **912** may, however, be any electrical device without departing from the scope of the invention.

As shown, the connector **902** comprises a plurality of lead assemblies **908**. Each lead assembly **908** comprises a column of terminals or conductors **930** therein as will be described below. Each lead assembly **908** comprises any number of terminals **930**.

FIG. **16**B is backplane system similar to FIG. **16**A except that the connector **903** is a single device rather than mating plug and receptacle. Connector **903** comprises a housing and a plurality of lead assemblies (not shown). The housing is configured to contain and align the plurality of lead assemblies (not shown) such that an electrical connection suitable for signal communication is made between a first electrical device **910** and a second electrical device **912**

FIG. **16**C is a board-to-board system similar to FIG. **16**A except that plug connector **905** is a vertical plug connector rather than a right angle plug connector. This embodiment makes electrical connection between two parallel electrical devices **910** and **913**. A vertical back-panel receptacle connector according to the invention can be insert molded onto a board, for example. Thus, spacing, and therefore performance, can be maintained.

FIG. **17** is a perspective view of the plug connector of FIG. **16**A shown without electrical devices **910** and **912** and receptacle connector **1100**. As shown, slots **907** are formed in the housing **905** that contain and align the lead assemblies **908** therein. FIG. **17** also shows connection pins **932**, **942**. Connection pins **942** connect connector **902** to electrical device **912**. Connection pins **932** electrically connect connector **902** to electrical device **910** via receptacle **1100**. Connection pins **932** and **942** may be adapted to provide through-mount or surface-mount connections to an electrical device (not shown).

In one embodiment, the housing **905** is made of plastic, however, any suitable material may be used. The connections to electrical devices **910** and **912** may be surface or through mount connections.

FIG. **18** is a side view of plug connector **902** as shown in FIG. **17**. As shown, the column of terminals contained in

each lead assembly **908** are offset from another column of terminals in an adjacent lead assembly by a distance d. Such an offset is discussed more fully above in connection with FIGS. **6** and **7**.

FIG. **19**A is a side view of a single lead assembly **908**. As shown in FIG. **19**A, one embodiment of lead assembly **908** comprises a metal lead frame **940** and an insert molded plastic frame **933**. In this manner, the insert molded lead assembly **933** serves to contain one column of terminals or conductors **930**. The terminals may comprise either differential pairs or ground contacts. In this manner, each lead assembly **908** comprises a column of differential pairs **935**A and **935**B and ground contacts **937**.

As is also shown in FIG. **19**A, the column of differential pairs and ground contacts contained in each lead assembly **908** are arranged in a signal-signal-ground configuration. In this manner, the top contact of the column of terminals in lead assembly **908** is a ground contact **937**A. Adjacent to ground contact **937**A is a differential pair **935**A comprised of a two signal contacts, one with a positive polarity and one with a negative polarity.

As shown, the ground contacts **937**A and **937**B extend a greater distance from the insert molded lead assembly **933**. As shown in FIG. **19**B, such a configuration allows the ground contacts **937** to mate with corresponding receptacle contacts **1102**G in receptacle **1100** before the signal contacts **935** mate with corresponding receptacle contacts **1102**S. Thus, the connected devices (not shown in FIG. **19**B) can be brought to a common ground before signal transmission occurs between them. This provides for "hot" connection of the devices.

Lead assembly **908** of connector **900** is shown as a right angle module. To explain, a set of first connection pins **932** is positioned on a first plane (e.g., coplanar with first electrical device **910**) and a set of second connection pins **942** is positioned on a second plane (e.g., coplanar with second electrical device **912**) perpendicular to the first plane. To connect the first plane to the second plane, each conductor **930** is formed to extend a total of about ninety degrees (a right angle) to electrically connect electrical devices **910** and **912**.

FIGS. **20** and **21** are side and front views, respectively, of two columns of terminals in accordance with one aspect of the invention. As shown in FIGS. **20** and **21**, adjacent columns of terminals are staggered in relation to one another. In other words, an offset exists between terminals in adjacent lead assemblies. In particular and as shown in FIGS. **20** and **21**, an offset of distance d exists between terminals in column **1** and terminals in column **2**. As shown, the offset d runs along the entire length of the terminal. As stated above, the offset reduces the incidence of cross talk by furthering the distance between the signal carrying contacts.

To simplify conductor placement, conductors **930** have a rectangular cross section as shown in FIG. **20**. Conductors **930** may, however, be any shape.

FIG. **22** is a perspective view of the receptacle portion of the connector shown in FIG. **16**A. Receptacle **1100** may be mated with connector plug **902** (as shown in FIG. **16**A) and used to connect two electrical devices (not shown). Specifically, connection pins **932** (as shown in FIG. **17**) may be inserted into aperatures **1142** to electrically connect connector **902** to receptacle **1100**. Receptacle **1100** also includes alignment structures **1120** to aid in the alignment and insertion of connector **900** into receptacle **1100**. Once inserted, structures **1120** also serve to secure the connector once inserted into receptacle **1100**. Such structures **1120** thereby prevent any movement that may occur between the connector and receptacle that could result in mechanical breakage therebetween.

Receptacle **1100** includes a plurality of receptacle contact assemblies **1160** each containing a plurality of terminals (only the tails of which are shown). The terminals provide the electrical pathway between the connector **900** and any mated electrical device (not shown).

FIG. **23** is a side view of the receptacle of FIG. **22** including structures **1120**, housing **1150** and receptacle lead assembly **1160**. As shown, FIG. **23** also shows that the receptacle lead assemblies may be offset from one another in accordance with the invention. As stated above, such offset reduces the occurrence of multi-active cross talk as described above.

FIG. **24** is a perspective view of a single receptacle contact assembly not contained in receptacle housing **1150**. As shown, the assembly **1160** includes a plurality of dual beam conductive terminals **1175** and a holder **1168** made of insulating material. In one embodiment, the holder **1168** is made of plastic injection molded around the contacts; however, any suitable insulating material may be used without departing from the scope of the invention.

FIG. **25** is a perspective view of a connector in accordance with another embodiment of the invention. As shown, connector **1310** and receptacle **1315** are used in combination to connect an electrical device, such as circuit board **1305** to a cable **1325**. Specifically, when connector **1310** is mated with receptacle **1315**, an electrical connection is established between board **1305** and cable **1325**. Cable **1325** can then transmit signals to any electrical device (not shown) suitable for receiving such signals.

In another embodiment of the invention, it is contemplated that the offset distance, d, may vary throughout the length of the terminals in the connector. In this manner, the offset distance may vary along the length of the terminal as well as at either end of the conductor. To illustrate this embodiment and referring now to FIG. **26**, a side view of a single column of right angle terminals is shown. As shown, the height of the terminals in section A is height H**1** and the height of the cross section of terminals in section B is height H**2**.

FIGS. **27** and **28** are front views of the columns of right angle terminals taken along lines A—A and lines B—B respectively. In addition to the single column of terminals shown in FIG. **26**, FIGS. **27** and **28** also show an adjacent column of terminals contained in the adjacent lead assembly contained in the connector housing.

In accordance with the invention, the offset of adjacent columns may vary along the length of the terminals within the lead assembly. More specifically, the offset between adjacent columns varies according to adjacent sections of the terminals. In this manner, the offset distance between columns is different in section A of the terminals than in section B of the terminals.

As shown in FIGS. **27** and **28**, the cross sectional height of terminals taken along line A—A in section A of the terminal is H_1 and the cross sectional height of terminals in section B taken along line B—B is height H_2. As shown in FIG. **27**, the offset of terminals in section A, where the cross sectional height of the terminal is H_1, is a distance D_1.

Similarly, FIG. **28** shows the offset of the terminals in section B of the terminal. As shown, the offset distance between terminals in section B of the terminal is D_2. Preferably, the offset D_2 is chosen to minimize crosstalk, and may be different from the offset D_2 because spacing or other

parameters are different. The multi-active cross talk that occurs between the terminals can thus be reduced, thereby increasing signal integrity.

In another embodiment of the invention, to further reduce cross talk, the offset between adjacent terminal columns is different than the offset between vias on a mated printed circuit board. A via is conducting pathway between two or more layers on a printed circuit board. Typically, a via is created by drilling through the printed circuit board at the appropriate place where two or more conductors will interconnect.

To illustrate such an embodiment, FIG. **29** illustrates a front view of a cross section of four columns of terminals as the terminals mate to vias on an electrical device. Such an electric device may be similar to those as illustrated in FIG. **16**A. The terminals **1710** of the connector (not shown) are inserted into vias **1700** by connection pins (not shown). The connection pins, however, may be similar to those shown in FIG. **17**.

In accordance with this embodiment of the invention, the offset between adjacent terminal columns is different than the offset between vias on a mated printed circuit board. Specifically, as shown in FIG. **29**, the distance between the offset of adjacent column terminals is D_c and the distance between the offset of vias in an electrical device is D_v. By varying these two offset distances to their optimal values in accordance with the invention, the cross talk that occurs in the connector of the invention is reduced and the corresponding signal integrity is maintained.

FIG. **30** is a perspective view of a portion of another embodiment of a right angle electrical connector **1100**. As shown in FIG. **30**, conductors **130** are positioned from a first plane to a second plane that is orthogonal to the first plane. Distance D between adjacent conductors **930** remains substantially constant, even though the width of conductor **930** may vary and even though the path of conductor **930** may be circuitous. This substantially constant gap D provides a substantially constant differential impedance along the length of the conductors.

FIG. **31** is a perspective view of another embodiment of a right angle electrical connector **1200**. As shown in FIG. **12**, modules **1210** are positioned in a frame **1220** to provide proper spacing between adjacent modules **1210**.

FIG. **32** is a perspective view of an alternate embodiment of a receptacle connector **1100'**. As shown in FIG. **32**, connector **1100'** comprises a frame **1190** to provide proper spacing between connection pins **1175'**. Frame **1190** comprises recesses, in which conductors **1175'** are secured. Each conductor **1175'** comprises a single contact interface **1191** and a connection pin **1192**. Each contact interface **1191** extends from frame **1190** for connection to a corresponding plug contact, as described above. Each connection pin **1942** extends from frame **1190** for electrical connection to a second electrical device. Receptacle connector **1190** may be assembled via a stitching process.

To attain desirable gap tolerances over the length of conductors **903**, connector **900** may be manufactured by the method as illustrated in FIG. **33**. As shown in FIG. **33**, at step **1400**, conductors **930** are placed in a die blank with predetermined gaps between conductors **930**. At step **1410**, polymer is injected into the die blank to form the frame of connector **900**. The relative position of conductors **930** are maintained by frame **950**. Subsequent warping and twisting caused by residual stresses can have an effect on the variability, but if well designed, the resultant frame **950** should have sufficient stability to maintain the desired gap tolerances. In this manner, gaps between conductors **930** can be controlled with variability of tenths of thousandths of an inch.

Preferably, to provide the best performance, the current carrying path through the connector should be made as highly conductive as possible. Because the current carrying path is known to be on the outer portion of the contact, it is desirable that the contacts be plated with a thin outer layer of a high conductivity material. Examples of such high conductivity materials include gold, copper, silver, a tin alloy.

It is to be understood that the foregoing illustrative embodiments have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the invention. Words which have been used herein are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular structure, materials and/or embodiments, the invention is not intended to be limited to the particulars disclosed herein. Rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the teachings of this specification, may affect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects.

What is claimed is:

1. An electrical connector, comprising:

a first column of electrical contacts comprising a first arrangement of differential signal pairs separated from one another by first ground contacts;

a second column of electrical contacts comprising a second arrangement of differential signal pairs separated from one another by second ground contacts, wherein one differential signal pair in the second arrangement of differential signal pairs is a victim differential signal pair; and

a third column of electrical contacts comprising a third arrangement of differential signal pairs separated from one another by third ground contacts,

wherein (i) the second column is adjacent to the first column, and the third column is adjacent to the second column; (ii) the connector is devoid of electrical shields between the first column and the second column, and between the second column and the third column; (iii) the contacts in the first column are spaced apart from the contacts in the second column by a column-spacing distance of about 1.8–2.0 millimeters and the contacts in the second column are spaced apart from the contacts in the third column by the column-spacing distance; (iv) each of the differential signal pairs defines a gap distance between the electrical contacts that form the pair; and (v) the gap distance relative to the column-spacing distance is such that differential signals with rise times of 200 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case, multi-active cross talk on the victim differential signal pair.

2. The electrical connector as claimed in claim **1**, wherein each differential signal pair comprises two electrical signal contacts that are tightly electrically coupled to one another.

3. The electrical connector as claimed in claim **1**, wherein a differential signal pair in the third column is offset from the victim differential signal pair by a row pitch.

4. The electrical connector as claimed in claim 1, wherein a differential signal pair in the third column is offset from the victim differential signal pair by an offset distance that is less than a row pitch.

5. The electrical connector as claimed in claim 1, wherein a differential signal pair in the third column is offset from the victim differential signal pair by more than a row pitch.

6. The electrical connector as claimed in claim 1, wherein the impedance of the first differential signal pair is between about 90 and 110 Ohms.

7. The electrical connector as claimed in claim 1, wherein the 200 picosecond rise time represents a data transfer rate greater than 1.25 Gigabits/sec and less than 2.5 Gigabits/sec.

8. The electrical connector as claimed in claim 1, wherein electrical contacts that form a differential signal pair in the first column extend from a mating face of the connector and one of the first ground contacts extend farther from the mating face than the electrical contacts.

9. The electrical connector as claimed in claim 1, wherein electrical contacts that form a differential pair in the first column each terminate at a respective end thereof with a corresponding fusible mounting element.

10. The electrical connector as claimed in claim 1, wherein the worst-case, multi-active cross talk on the victim differential signal pair is 4% or less.

11. The electrical connector as claimed in claim 1, wherein the worst-case, multi-active cross talk on the victim differential signal pair is 3% or less.

12. The electrical connector as claimed in claim 1, wherein the electrical connector has an insertion loss of less than about 0.7 dB at 5 GHz.

13. The electrical connector as claimed in claim 1, wherein the differential signal pairs are broadside coupled.

14. The electrical connector as claimed in claim 1, wherein the gap distance relative to the column-spacing distance is such that differential signals with rise times of 150 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case cross talk on the victim differential signal pair.

15. The electrical connector as claimed in claim 14, wherein the 150 picosecond rise time represents a data transfer rate of about 2.5 Gigabits/sec.

16. The electrical connector as claimed in claim 1, wherein the gap distance relative to the column-spacing distance is such that differential signals with rise times of 100 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case cross talk on the victim differential signal pair.

17. The electrical connector as claimed in claim 16, wherein the 100 picosecond rise time represents a data transfer rate of about 3.2 Gigabits/sec.

18. The electrical connector as claimed in claim 1, wherein the gap distance relative to the column-spacing distance is such that differential signals with rise times of 50 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case cross talk on the victim differential signal pair.

19. The electrical connector as claimed in claim 18, wherein the 50 picosecond rise time represents a data transfer rate greater than 4.8 Gigabits/sec and less than 10 Gigabits/sec.

20. The electrical connector as claimed in claim 1, wherein the gap distance relative to the column-spacing distance is such that differential signals with rise times of 40 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than 6% worst-case cross talk on the victim differential signal pair.

21. The electrical connector as claimed in claim 20, wherein the 40 picosecond rise time represents a data transfer rate of about 10 Gigabits/sec.

22. An electrical connector comprising:

a first electrical connector half and a second electrical connector half that mates with the first electrical connector half, the first electrical connector half and the second electrical connector half each comprising:

a first column of electrical contacts comprising a first differential signal pair of electrical contacts, a first ground contact adjacent to the first differential signal pair, a second differential signal pair of electrical contacts adjacent to the first ground contact, a second ground contact adjacent to the second differential signal pair, and a third differential signal pair of electrical contacts adjacent to the second ground contact;

a second column of electrical contacts comprising a fourth differential signal pair of electrical contacts, a third ground contact adjacent to the fourth differential signal pair, a fifth differential signal pair of electrical contacts adjacent to the third ground contact, a fourth ground contact adjacent to the fifth differential signal pair, and a sixth differential signal pair of electrical contacts adjacent to the fourth ground contact; and

a third column of electrical contacts comprising a seventh differential signal pair of electrical contacts, a fifth ground contact adjacent to the seventh differential signal pair, an eighth differential signal pair of electrical contacts adjacent to the fifth ground contact, a sixth ground contact adjacent to the eighth differential signal pair, and a ninth differential signal pair of electrical contacts adjacent to the sixth ground contact,

wherein (i) the second column of electrical contacts is adjacent to the first column of electrical contacts and the third column of electrical contacts; (ii) the connector is devoid of electrical shields between the first, second, and third columns; (iii) the electrical contacts in the first column are spaced apart from the electrical contacts in the second column by a column-spacing distance, and the contacts in the second column are spaced apart from the contacts in the third column by the column-spacing distance; (iv) the electrical contacts that comprise the first differential signal pair are spaced apart by a gap distance that is less than the column-spacing distance; and (v) differential signals with rise times of 40 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the fifth differential signal pair produce no more than 600 worst-case, multi-active cross talk on the fifth differential signal pair.

23. The electrical connector as claimed in claim 22, wherein electrical signal contacts in the first differential signal pair are tightly electrically coupled to each other.

24. The electrical connector as claimed in claim 22, wherein the fourth differential signal pair is offset from the first differential signal pair by a row pitch.

25. The electrical connector as claimed in claim 22, wherein the fourth differential signal pair is offset from the first differential signal pair by an offset distance that is less than a row pitch.

26. The electrical connector as claimed in claim 22, wherein the fourth differential signal pair is offset from the first differential signal pair by more than a row pitch.

27. The electrical connector as claimed in claim 22, wherein the impedance of the first differential signal pair is between about 90 and 110 Ohms.

28. The electrical connector as claimed in claim 22, wherein the worst-case, multi-active, cross-talk on the fifth differential signal pair is 3% or less.

29. The electrical connector as claimed in claim 22, wherein the 40 picosecond rise time represents a data transfer rate of about 10 Gigabits/sec.

30. The electrical connector as claimed in claim 22, wherein electrical contacts that form a differential signal pair in the first column of the first connector extend from a mating face of the first electrical connector and one of the first ground contacts extends farther from the mating face than the electrical contacts.

31. The electrical connector as claimed in claim 22, wherein electrical contacts that form the first differential signal pair each terminate at a respective end thereof with a corresponding fusible mounting element.

32. The electrical connector as claimed in claim 22, wherein worst-case, multi-active cross talk on the fifth differential signal pair is 4% or less.

33. The electrical connector as claimed in claim 22, wherein worst-case, multi-active cross talk on the fifth differential signal pair is 3% or less.

34. The electrical connector as claimed in claim 22, wherein the electrical connector has an insertion loss of less than about 0.7 dB at 5 GHz.

35. The electrical connector as claimed in claim 22, wherein the differential signal pairs are broadside coupled.

36. The electrical connector as claimed in claim 22, wherein differential signals with rise times of 150 picoseconds in each of the six closest differential signal pairs produce no more than 6% worst-case, multi-active cross talk on the fifth differential signal pair.

37. The electrical connector as claimed in claim 36, wherein the 150 picosecond rise time represents a data transfer rate of about 2.5 Gigabits/sec.

38. The electrical connector as claimed in claim 22, wherein differential signals with rise times of 100 picoseconds in each of the six closest differential signal pairs produce no more than 60% worst-case, multi-active cross talk on the fifth differential signal pair.

39. The electrical connector as claimed in claim 38, wherein the 100 picosecond rise time represents a data transfer rate of about 3.2 Gigabits/sec.

40. The electrical connector as claimed in claim 22, wherein differential signals with rise times of 50 picoseconds in each of the six closest differential signal pairs produce no more than 6% worst-case, multi-active cross talk on the fifth differential signal pair.

41. The electrical connector as claimed in claim 40, wherein the 50 picosecond rise time represents a data transfer rate greater than 4.8 Gigabits/sec and less than 10 Gigabits/sec.

42. The electrical connector as claimed in claim 22, wherein differential signals with rise times of 200 picoseconds in each of the six closest differential signal pairs produce no more than 6% worst-case, multi-active cross talk on the fifth differential signal pair.

43. The electrical connector as claimed in claim 42, wherein the 200 picosecond rise time represents a data transfer rate greater than 1.25 Gigabits/sec and less than 2.5 Gigabits/sec.

44. An electrical connector comprising:

a first column of electrical contacts comprising a first arrangement of differential signal pairs each separated from one another by first ground contacts;

a second column of electrical contacts comprising a second arrangement of differential signal pairs each separated from one another by second ground contacts, wherein one differential signal pair in the second arrangement of differential signal pairs is a victim pair; and

a third column of electrical contacts comprising a third arrangement of differential signal pairs each separated from one another by third ground contacts,

wherein (i) the second column is adjacent to the first column, and the third column is adjacent to the second column (ii) the connector is devoid of electrical shields between the first column and the second column, and between the second column and the third column; (iii) the first column, the second column, and the third column are evenly spaced apart from one another by an equal column-spacing distance of about 1.8 to 2 millimeters; (iv) each of the differential signal pairs defines a gap distance between electrical contacts that form each differential signal pair; and (v) the gap distance relative to the column-spacing distance is such that differential signals with rise times of 40 picoseconds in the six differential signal pairs in the first, second, and third columns that are closest to the victim pair produce no more than an acceptable level of worst-case, multi-active cross talk on the victim pair.

45. The electrical connector as claimed in claim 44, wherein electrical contacts that form the first differential signal pair each terminate at a respective end thereof with a corresponding fusible mounting element.

46. The electrical connector as claimed in claim 44, wherein the impedance of the first differential signal pair is between about 90 and 110 Ohms.

47. The electrical connector as claimed in claim 44, wherein the first ground contact is tightly electrically coupled to one electrical contact in the first differential signal pair.

48. The electrical connector as claimed in claim 44, wherein the first linear array is staggered relative to the second linear array.

49. The electrical connector as claimed in claim 44, wherein the differential signal pairs are broadside coupled.

50. The electrical connector as claimed in claim 44, wherein the gap distance is approximately 0.3 to 0.4 millimeters.

51. The electrical connector as claimed in claim 50, wherein the column-spacing distance defines a column pitch between the first linear array and the second linear array, and the gap distance is based on the column pitch.

52. The electrical connector as claimed in claim 51, wherein the gap distance is between approximately one-tenth of the column pitch and one-fifth of the column pitch.

53. The electrical connector as claimed in claim 51, wherein the gap distance is between approximately one-tenth of the column pitch and one-eighth of the column pitch.

54. The electrical connector as claimed in claim 51, wherein the gap distance is approximately one-fifth of the column pitch.

55. The electrical connector as claimed in claim 51, wherein the column pitch is approximately two millimeters and the gap distance is between approximately 0.3 millimeters and 0.4 millimeters.

56. An electrical connector comprising:

a first linear array of electrical contacts comprising

a first signal contact that defines a first side and a first edge, wherein the first side is two or more times greater in length than the first edge;

a second signal contact positioned adjacent to the first signal contact, wherein the second signal contact defines a second side and a second edge and the second side is two or more times greater in length that the second edge; and

a first ground contact positioned adjacent to the first signal contact; and a second linear array of electrical contacts comprising

a third signal contact that defines a third side and a third edge, wherein the third side is two or more times greater in length than the third edge;

a fourth signal contact positioned adjacent to the third signal contact, wherein the fourth signal contact defines a fourth side and a fourth edge and the fourth side is two or more times greater in length that the fourth edge; and

a second ground contact positioned along an imaginary line that is perpendicular to the first linear array of electrical contacts,

wherein (i) the first signal contact and the second signal contact are positioned edge-to-edge and form a first differential signal pair; (ii) the third signal contact and the fourth signal contact are positioned edge-to-edge and form a second differential signal pair; (iii) the first signal contact is positioned along the imaginary line that is perpendicular to the first linear array of electrical contacts; (iv) the connector is devoid of electrical shields between the first linear array of electrical contacts and the second linear array of electrical contacts; (v) a gap distance between the first and second signal contacts is less than a distance between the first signal contact and the second ground contact, and (vi) electrical contacts that form the first differential signal pair each terminate at a respective end thereof with a corresponding fusible mounting element.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,114,964 B2
APPLICATION NO. : 11/052167
DATED : October 3, 2006
INVENTOR(S) : Clifford L. Winings et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page, item should read
-- (63) Continuation of application No. 10/294,966, filed on Nov. 14, 2002, now Pat No. 6,976,886, which is a continuation-in-part of application No. 10/155,786, filed on May 24, 2002, now Pat. No. 6,652,318, **and is a** continuation-in-part of application No. 09/990,794, filed on Nov. 14, 2001, now Pat. No. 6,692,272. --

Col. 19, line 9 (Claim 6), delete "**first**" and substitute therefor **--victim--**.

Col. 19, line 17 (Claim 8), delete "**extend**" and substitute therefor **--extends--**.

Col. 20, line 59 (Claim 22), delete "**600**" and substitute therefor **--6%--**.

Col. 21, line 19 (claim 30), after "**connector**" insert **--half--**.

Col. 21, line 20 (claim 30), after "**connector**" insert **--half--**.

Col. 22, line 36 (claim 45), delete "**first**" and substitute therefor **--victim --**.

Col. 22, line 40 (claim 46), delete "**first**" and substitute therefor **--victim --**.

Col. 22, line 43 (claim 47), delete "**the first ground contact**" and substitute therefor **--one of the first ground contacts--**; at line 44, delete "**first**" and substitute therefor **--victim--**.

Col. 22, line 47 (claim 48), delete "**linear array**" and substitute therefor **--column--**; at line 48, delete "**linear array**" and substitute therefor **--column--**.

Col. 22, line 56 (claim 51), delete "**first linear array**" and substitute therefor **--first column--**; delete "**second linear array**" and substitute therefor **--second column--**.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

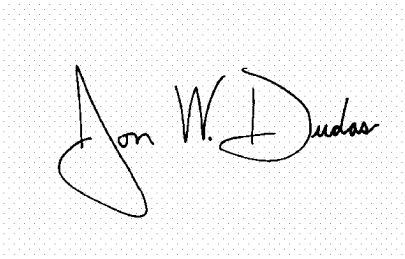
PATENT NO. : 7,114,964 B2
APPLICATION NO. : 11/052167
DATED : October 3, 2006
INVENTOR(S) : Clifford L. Winings et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At col. 21, line 49 (claim 38), delete "60%" and substitute therefor --6%--

Signed and Sealed this

Nineteenth Day of December, 2006



JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT C

US007182643B2

(12) **United States Patent**
Winings et al.

(10) **Patent No.: US 7,182,643 B2**
(45) **Date of Patent: Feb. 27, 2007**

(54) **SHIELDLESS, HIGH-SPEED ELECTRICAL CONNECTORS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/326,175**

(22) Filed: **Jan. 5, 2006**

(65) **Prior Publication Data**

US 2006/0234532 A1 Oct. 19, 2006

Related U.S. Application Data

(63) Continuation of application No. 10/634,547, filed on Aug. 5, 2003, now Pat. No. 6,994,569, which is a continuation-in-part of application No. 10/294,966, filed on Nov. 14, 2002, now Pat. No. 6,976,886, which is a continuation-in-part of application No. 09/990,794, filed on Nov. 14, 2001, now Pat. No. 6,692,272, and a continuation-in-part of application No. 10/155,786, filed on May 24, 2002, now Pat. No. 6,652,318.

(51) **Int. Cl.**
H01R 13/648 (2006.01)

(52) **U.S. Cl.** **439/608**; 439/79; 439/941

(58) **Field of Classification Search** 439/608, 439/79, 941, 701
See application file for complete search history.

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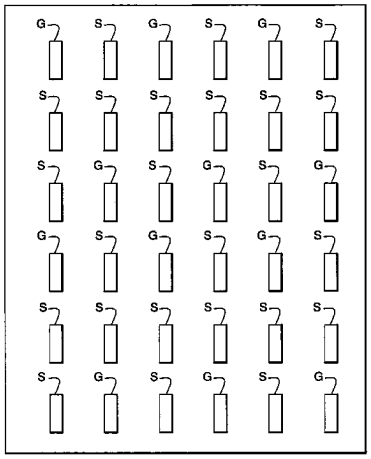
(Continued)

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(74) *Attorney, Agent, or Firm*—Woodcock Washburn LLP

(57) **ABSTRACT**

An electrical connector that includes a linear array of electrical blade contacts is disclosed. Each contact may have a free-ended mating portion that extends from a mate surface of a dielectric base. The first linear array may include a first signal contact, a second signal contact positioned adjacent to the first signal contact and forming a differential signal pair therewith, and a ground contact positioned adjacent to the second signal contact. The first signal contact, the second signal contact, and the ground contact may each be elongated in a direction along the linear array.

9 Claims, 68 Drawing Sheets



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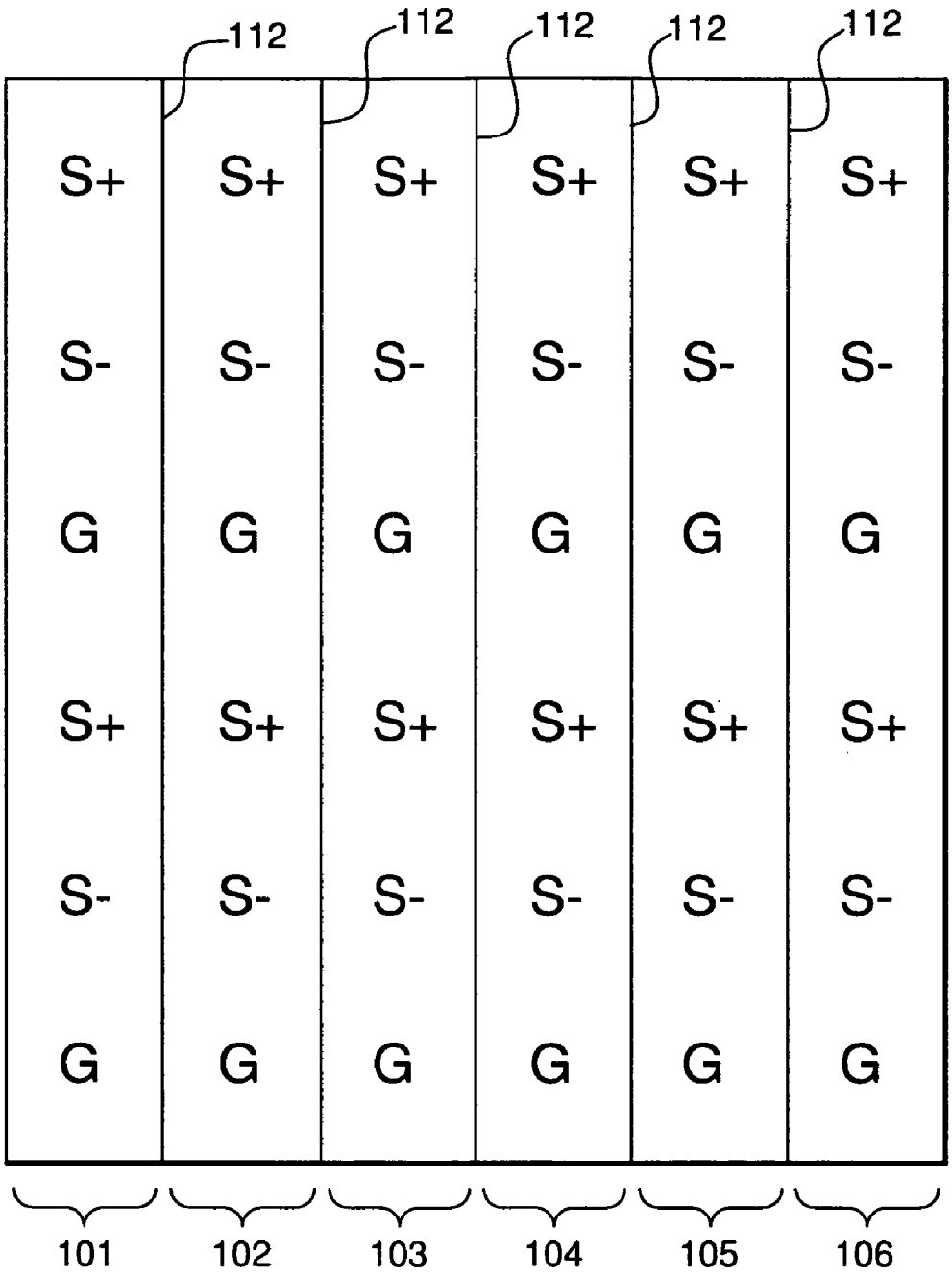


FIG. 1A
(PRIOR ART)

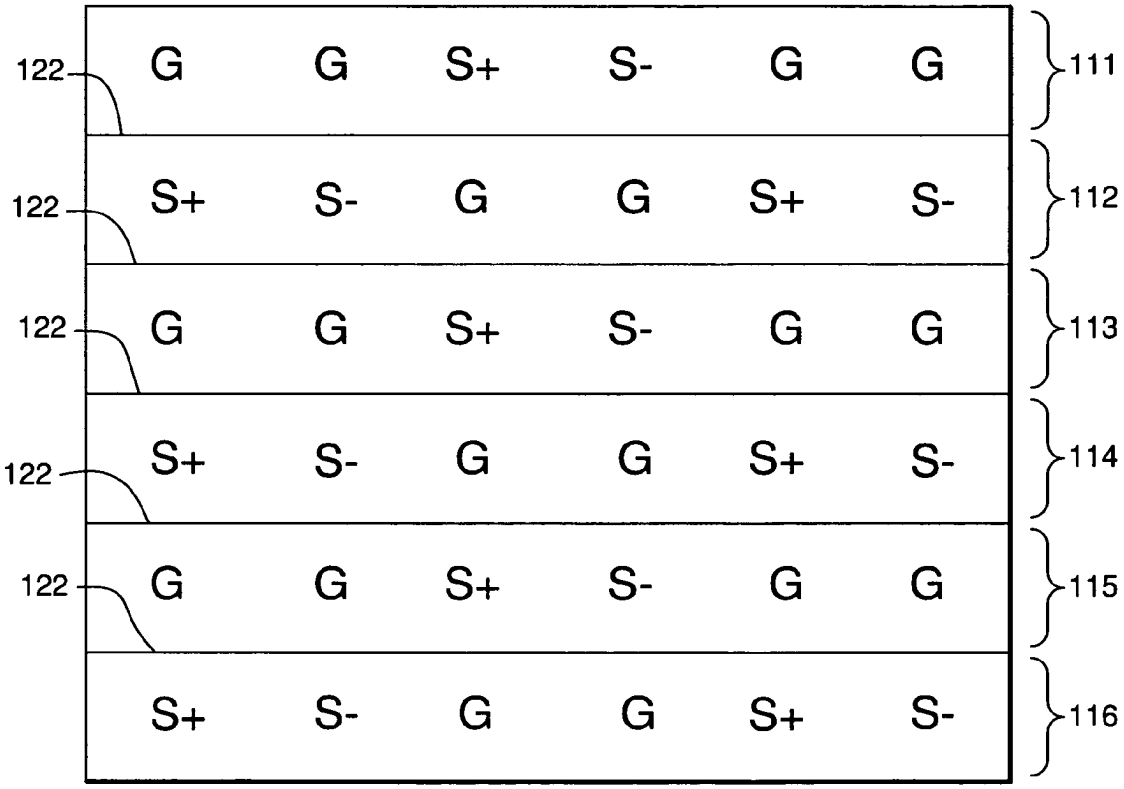


FIG. 1B
(PRIOR ART)

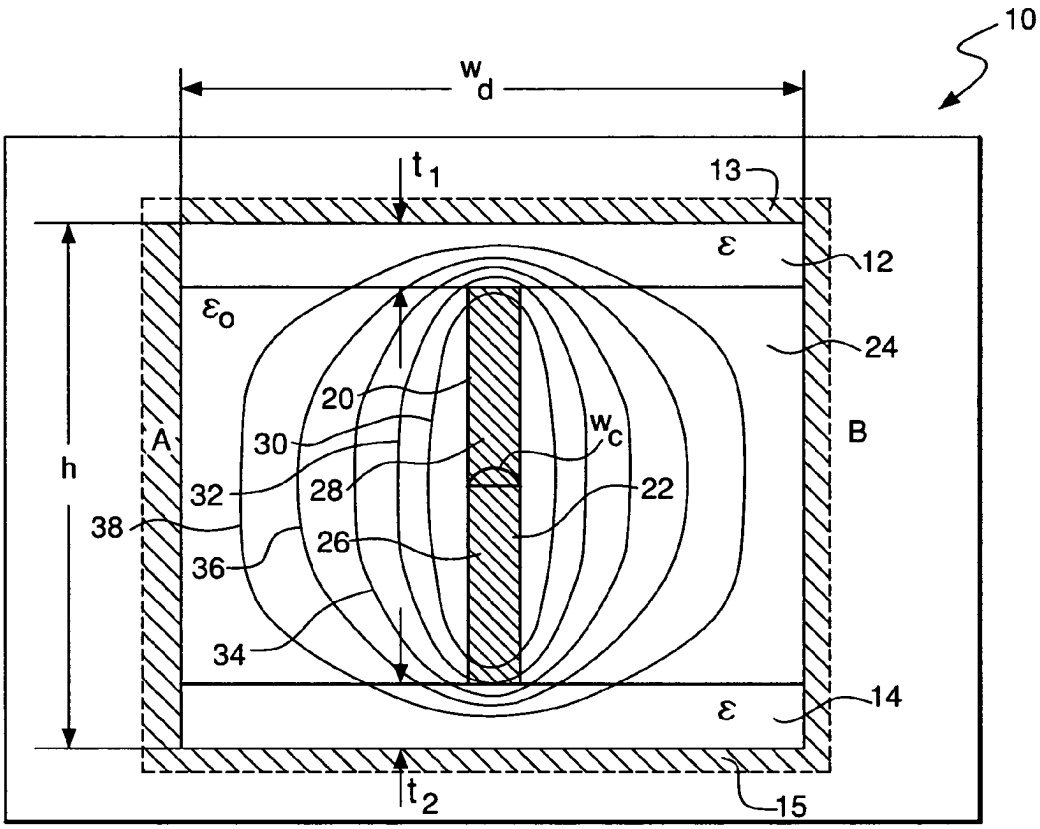

10
w_d
t_1
13
ε
12
ε_o
24
20
A
30
w_c
B
h
32
28
22
38
26
36
34
ε
14
t_2
15

FIG. 2A

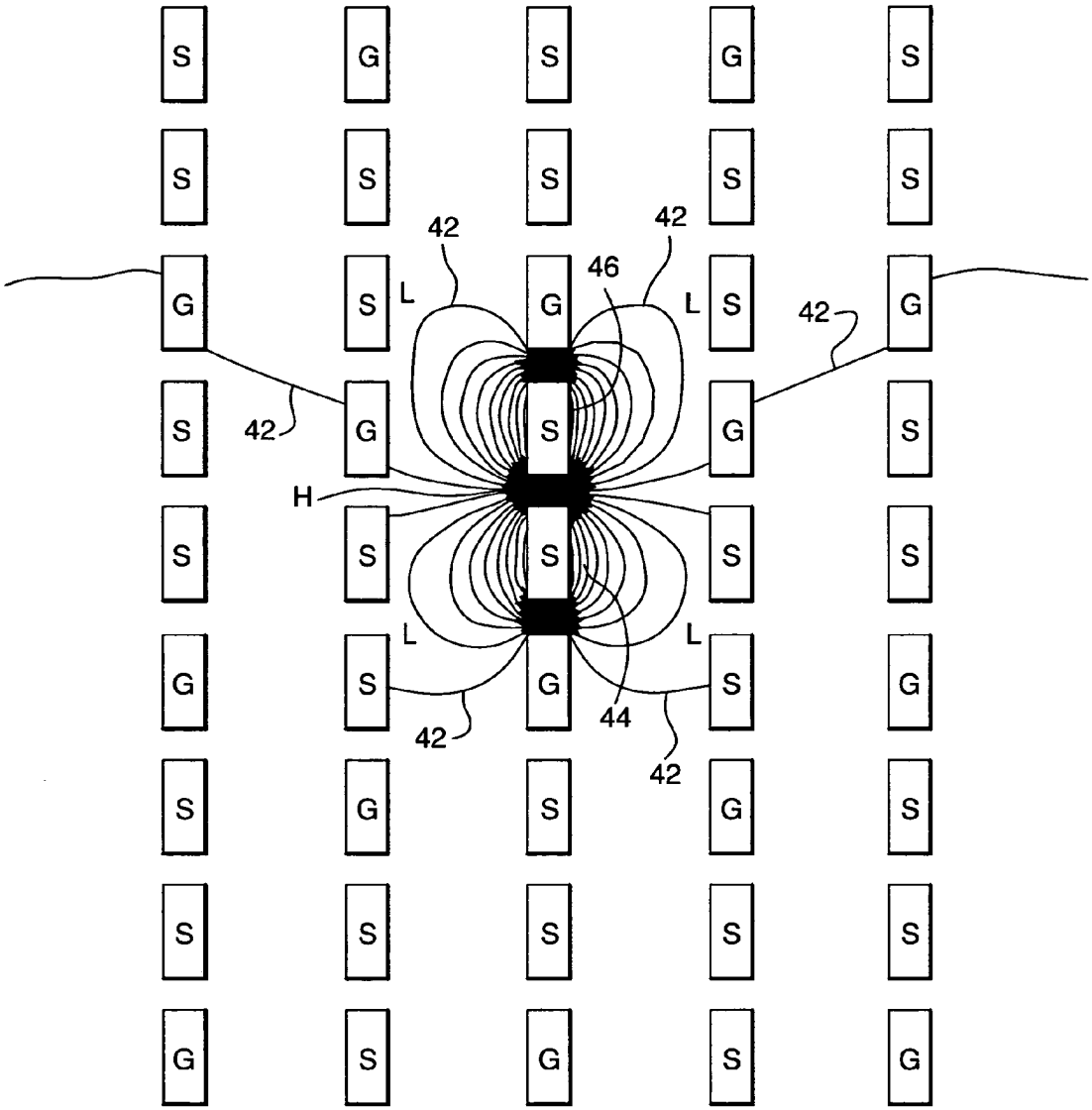


FIG. 2B

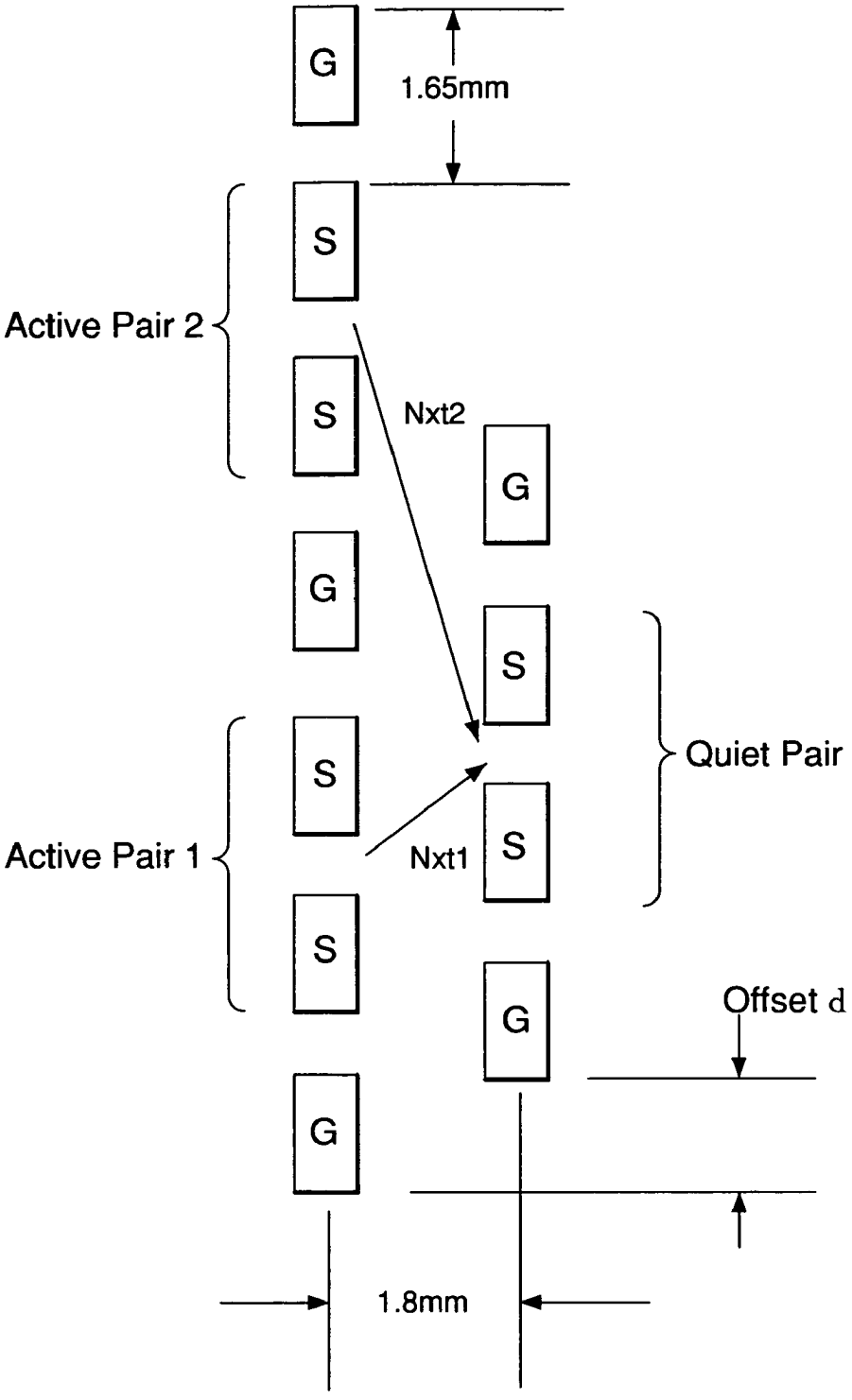

G
1.65mm
S
Active Pair 2
S
Nxt2
G
G
S
Quiet Pair
S
Active Pair 1
Nxt1
S
S
G
Offset d
G
1.8mm

FIG. 3A

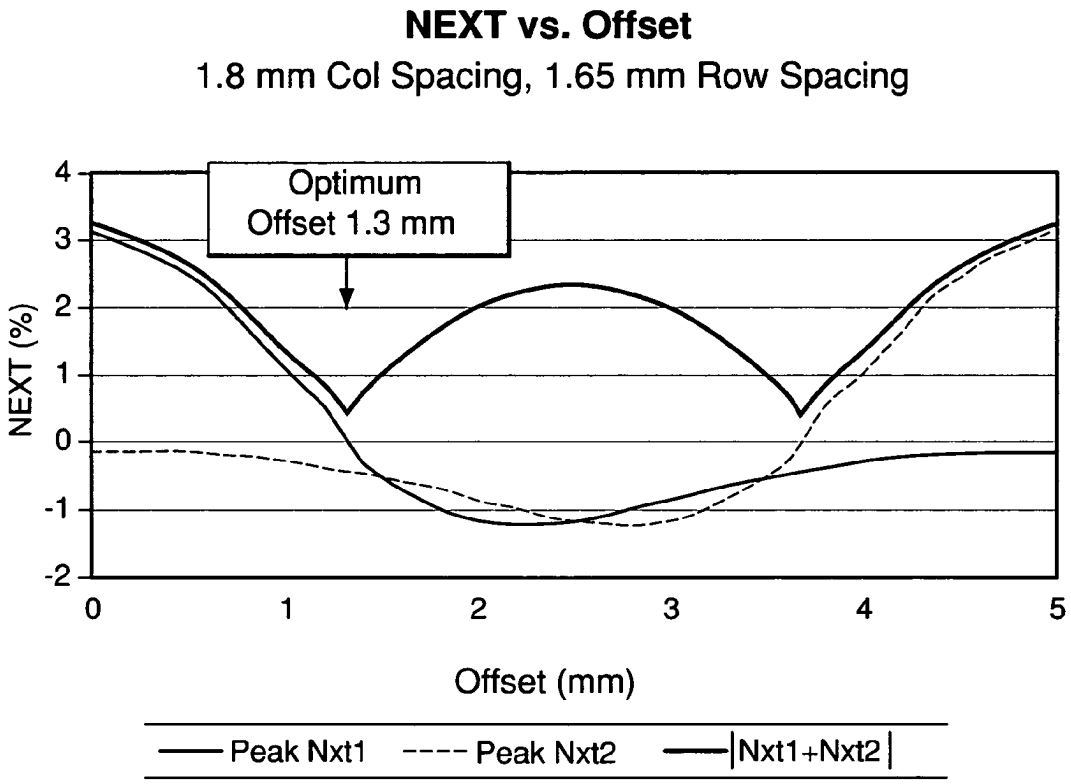

NEXT vs. Offset
1.8 mm Col Spacing, 1.65 mm Row Spacing
Optimum
Offset 1.3 mm
NEXT (%)
4
3
2
1
0
-1
-2
0
1
2
3
4
5
Offset (mm)
Peak Nxt1
Peak Nxt2
|Nxt1+Nxt2|

FIG. 3B

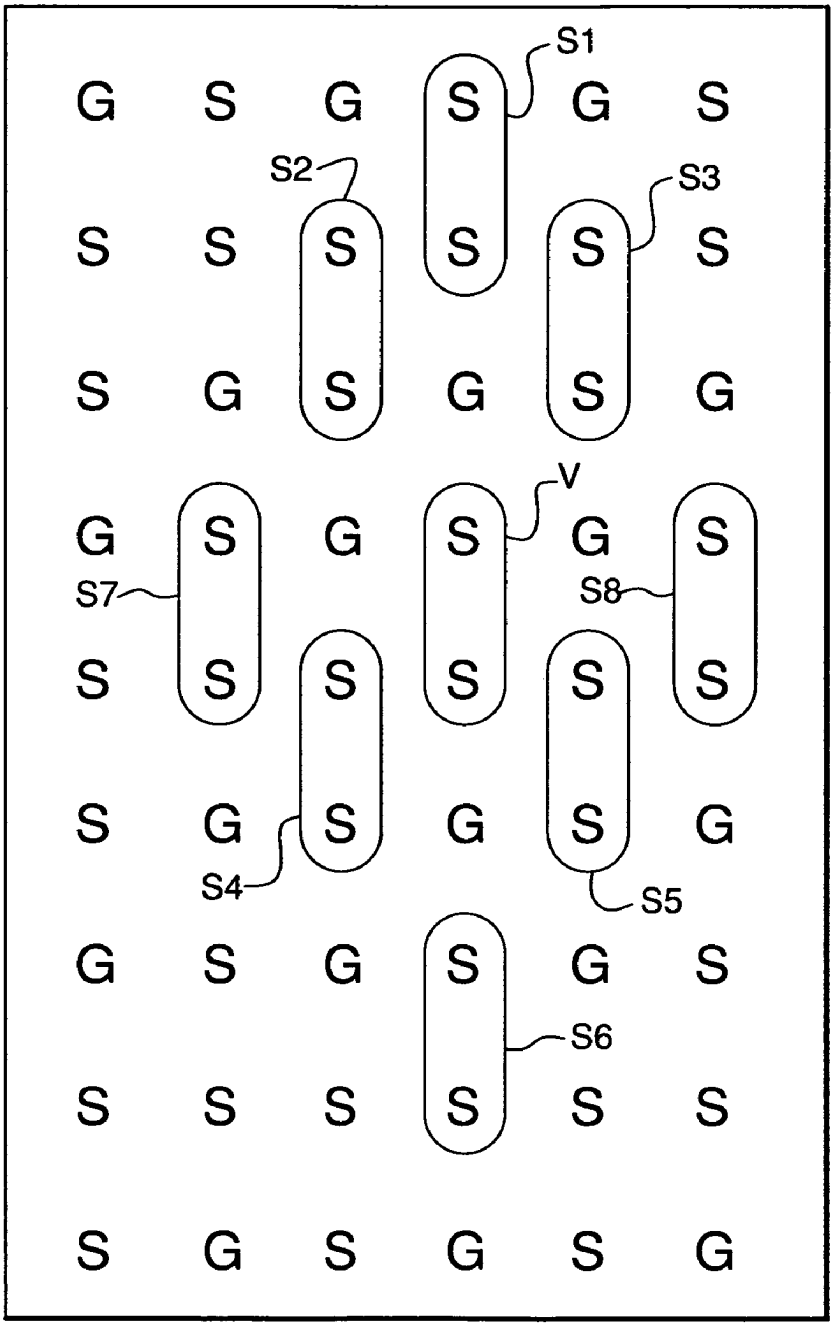


FIG. 3C

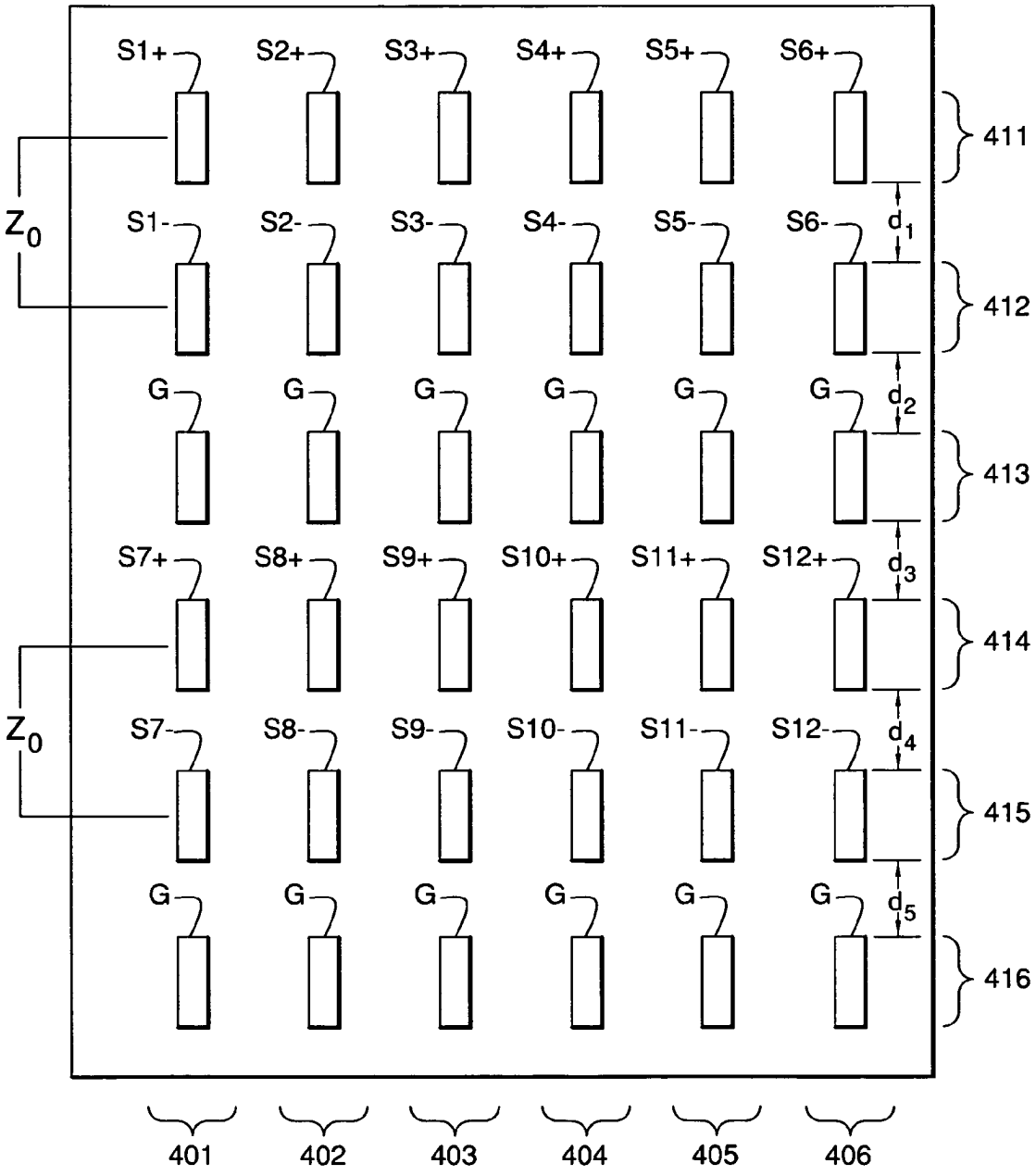

S1+
S2+
S3+
S4+
S5+
S6+
411
Z_0
S1-
S2-
S3-
S4-
S5-
S6-
d_1
412
G
d_2
413
S7+
S8+
S9+
S10+
S11+
S12+
d_3
414
Z_0
S7-
S8-
S9-
S10-
S11-
S12-
d_4
415
d_5
416
401
402
403
404
405
406

FIG. 4A

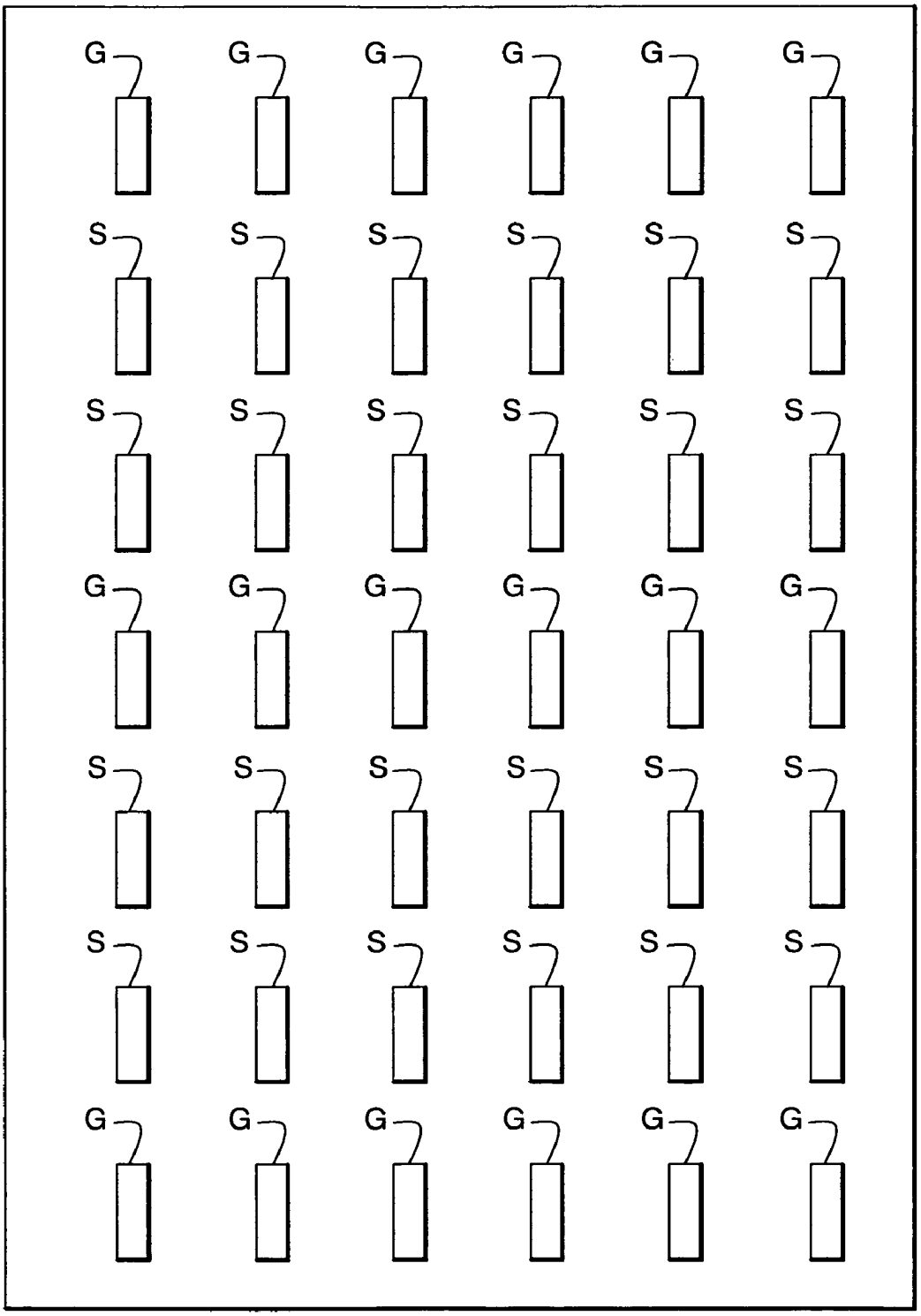


FIG. 4B

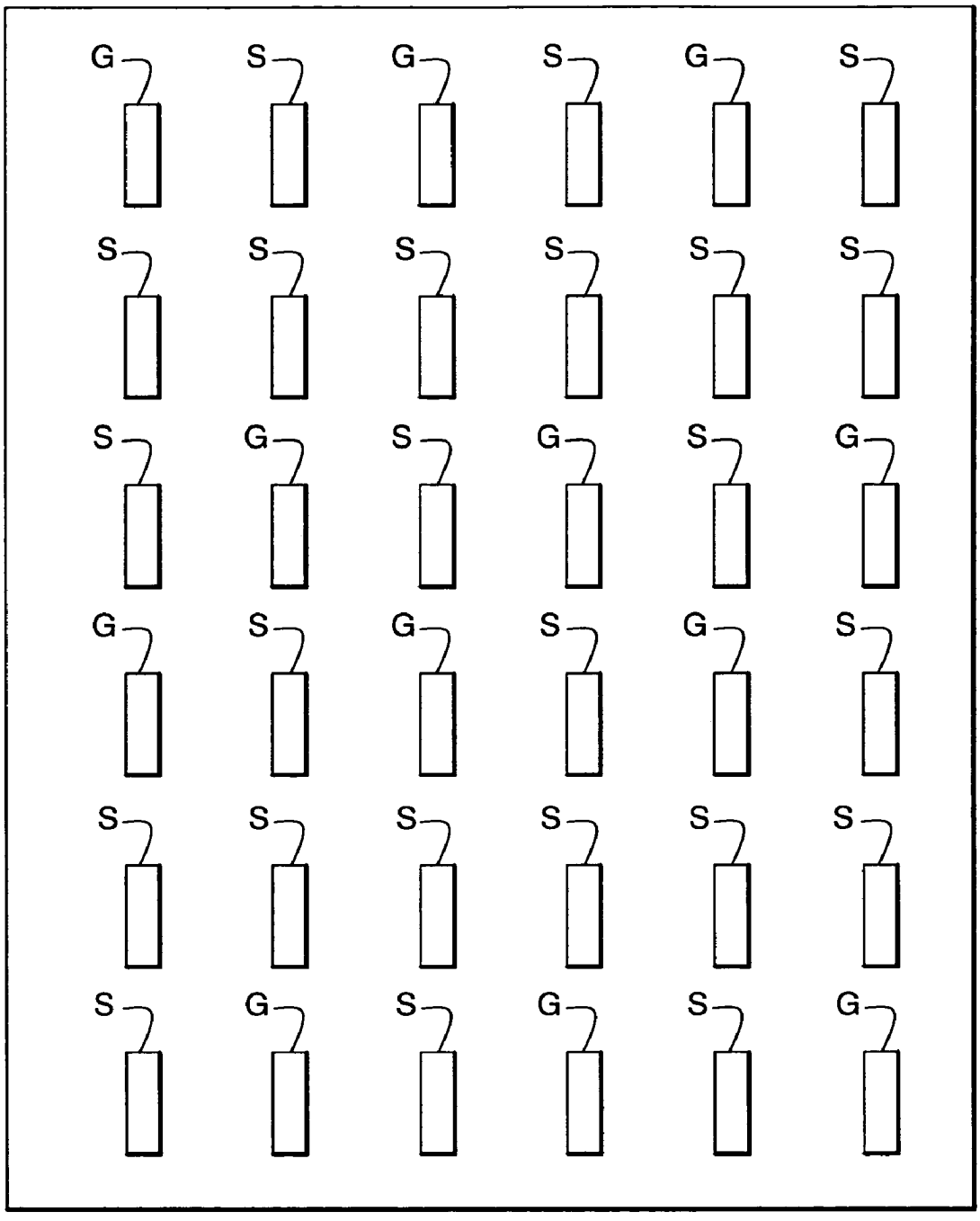


FIG. 4C

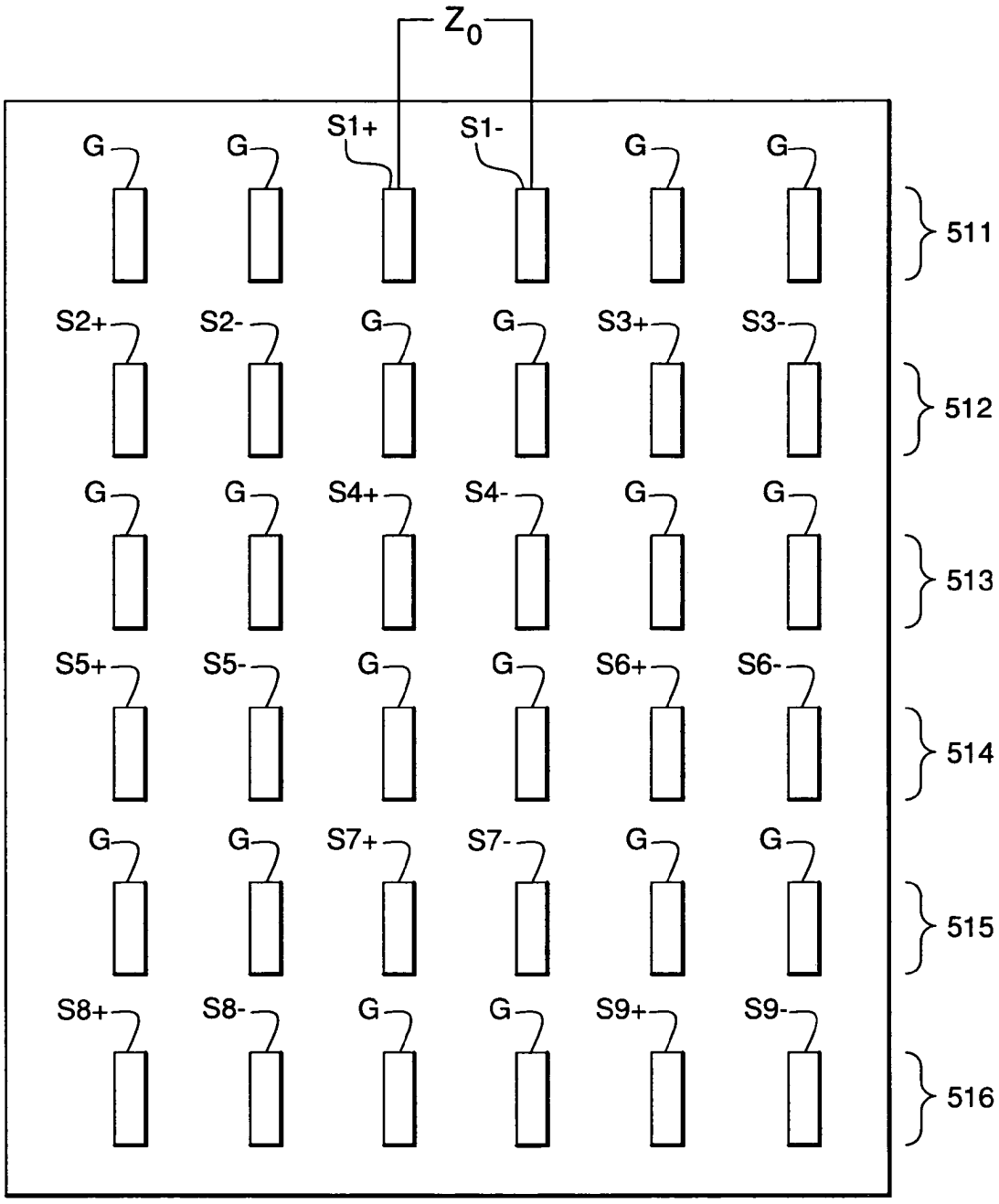

Z0
G
G
S1+
S1-
G
G
511
S2+
S2-
G
G
S3+
S3-
512
G
G
S4+
S4-
G
G
513
S5+
S5-
G
G
S6+
S6-
514
G
G
S7+
S7-
G
G
515
S8+
S8-
G
G
S9+
S9-
516

FIG. 5

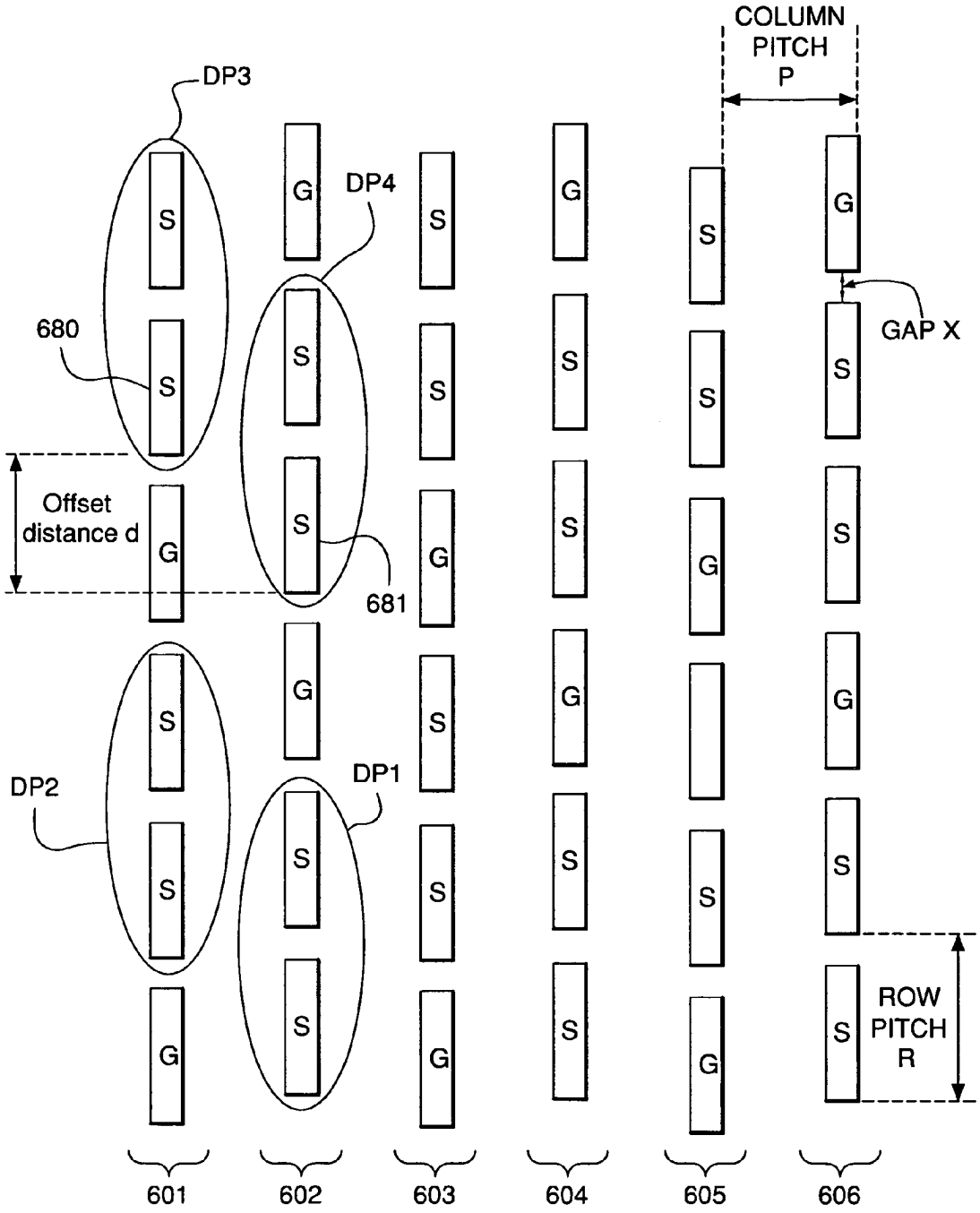

COLUMN
PITCH
P
DP3
DP4
680
GAP X
Offset
distance d
681
DP2
DP1
ROW
PITCH
R
S
G
601
602
603
604
605
606

FIG. 6

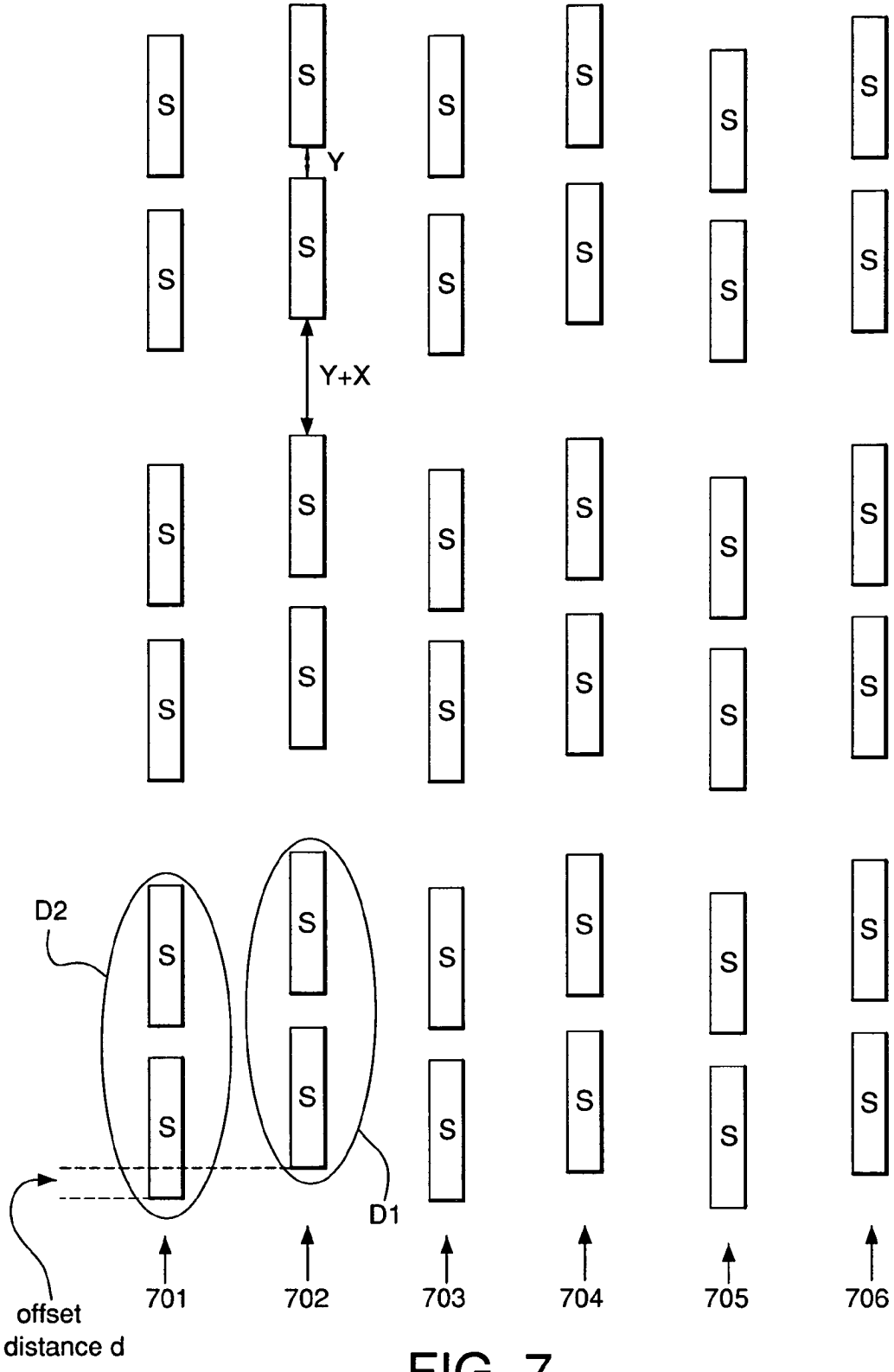


FIG. 7

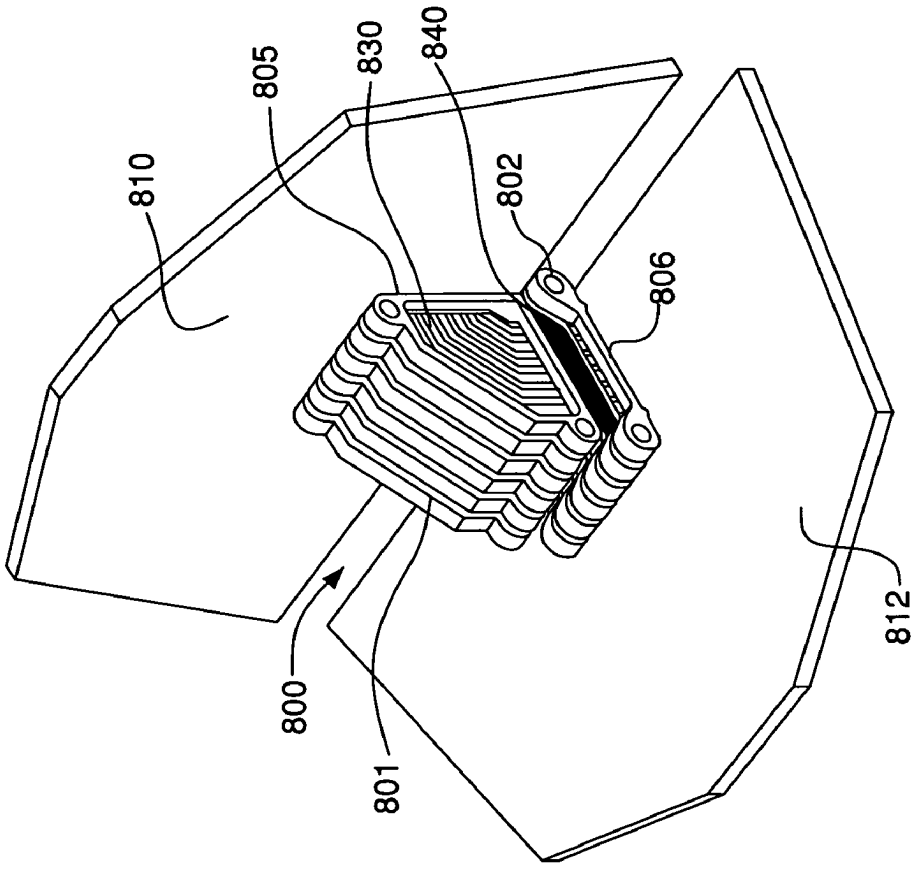


FIG. 8

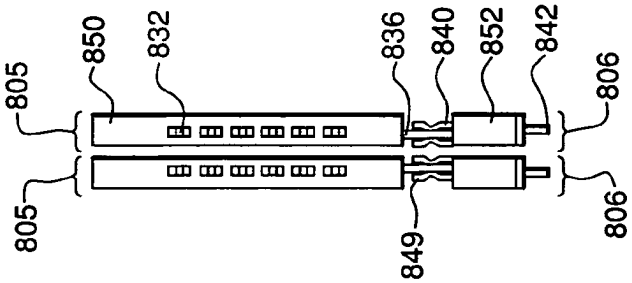


FIG. 10

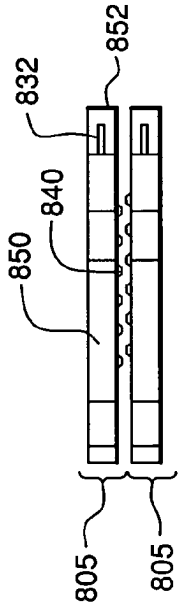


FIG. 11

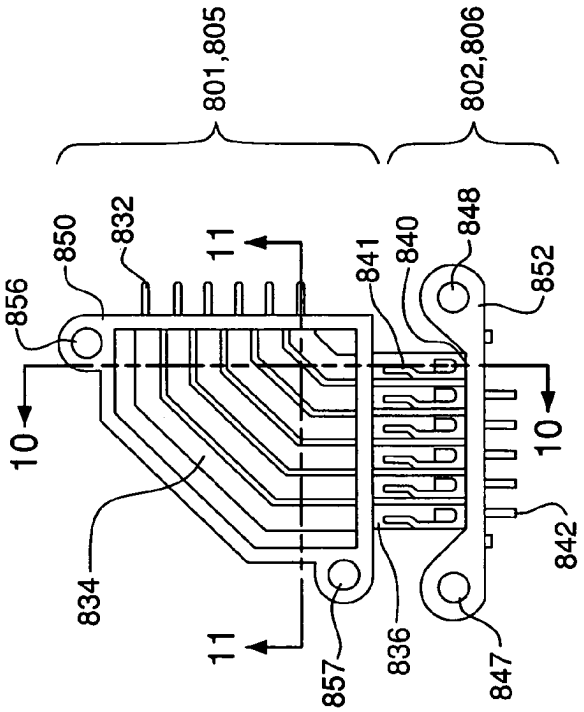


FIG. 9

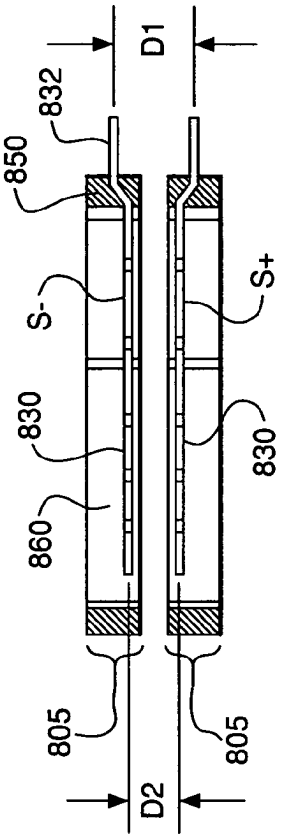


FIG. 12

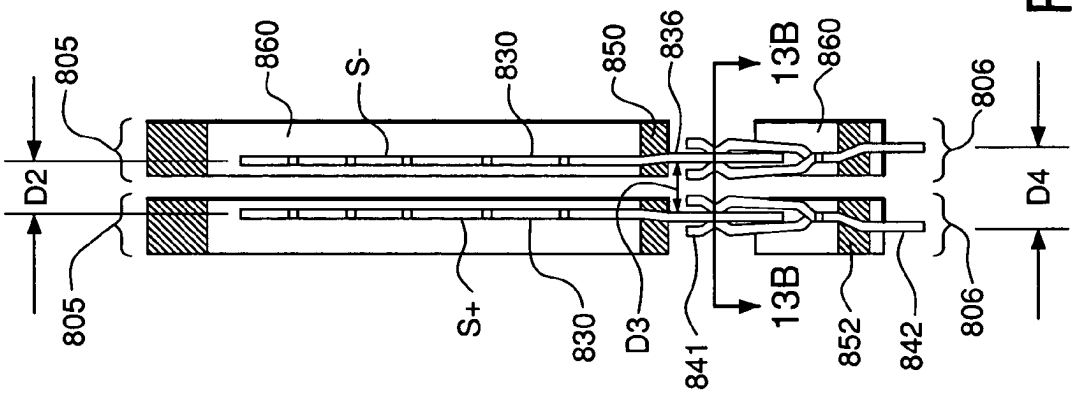


FIG. 13A

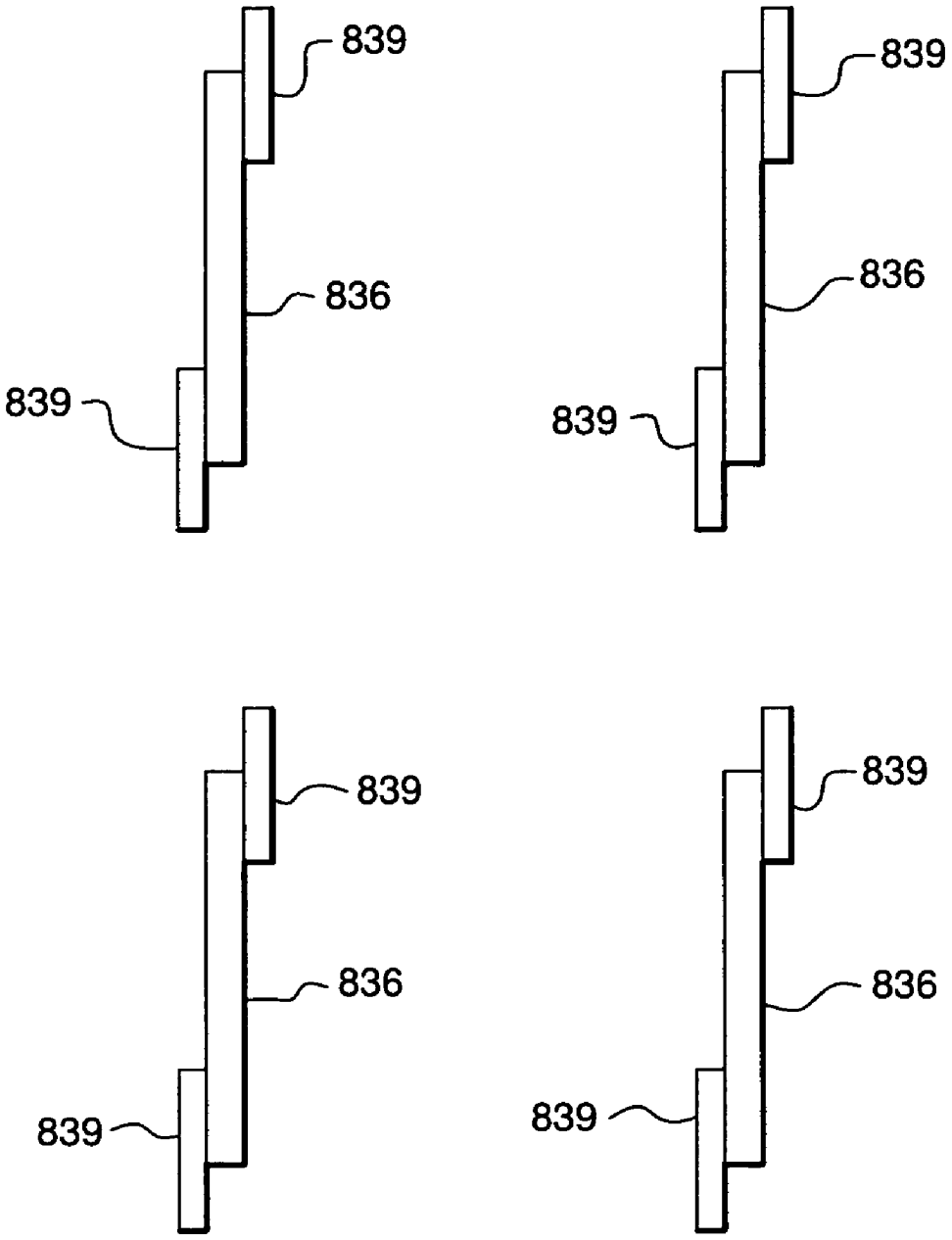


FIG. 13B

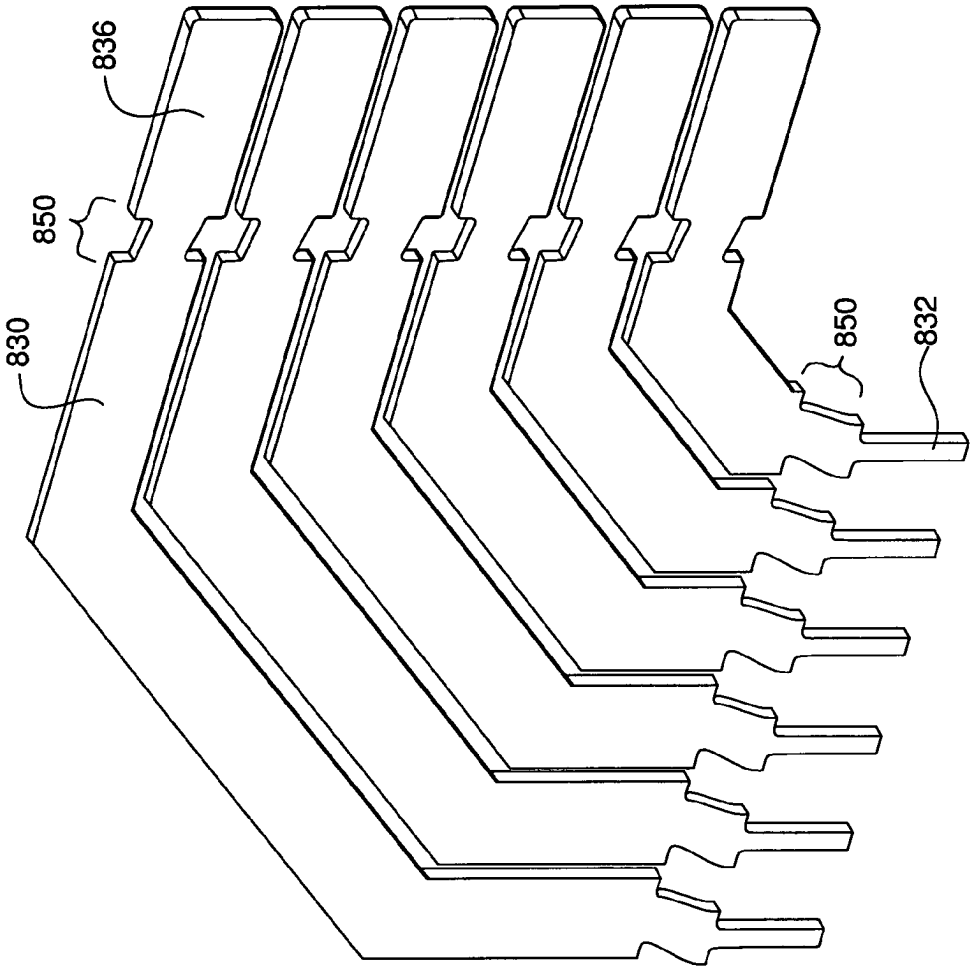


FIG. 14

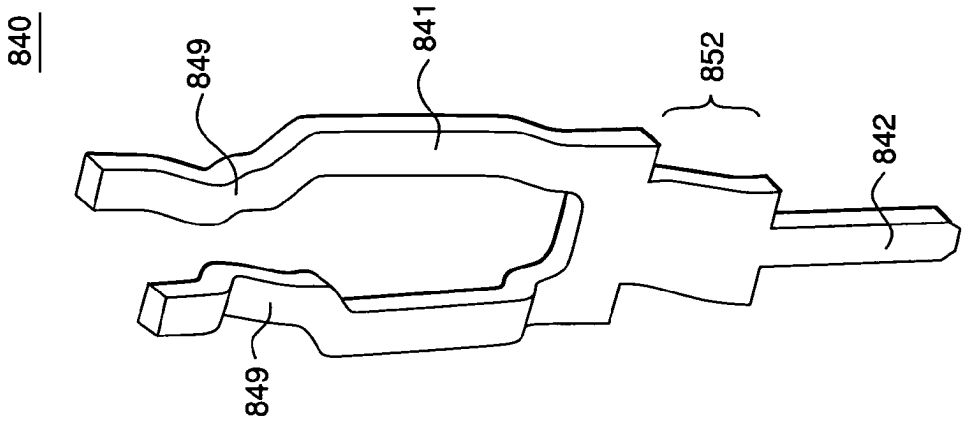


FIG. 15

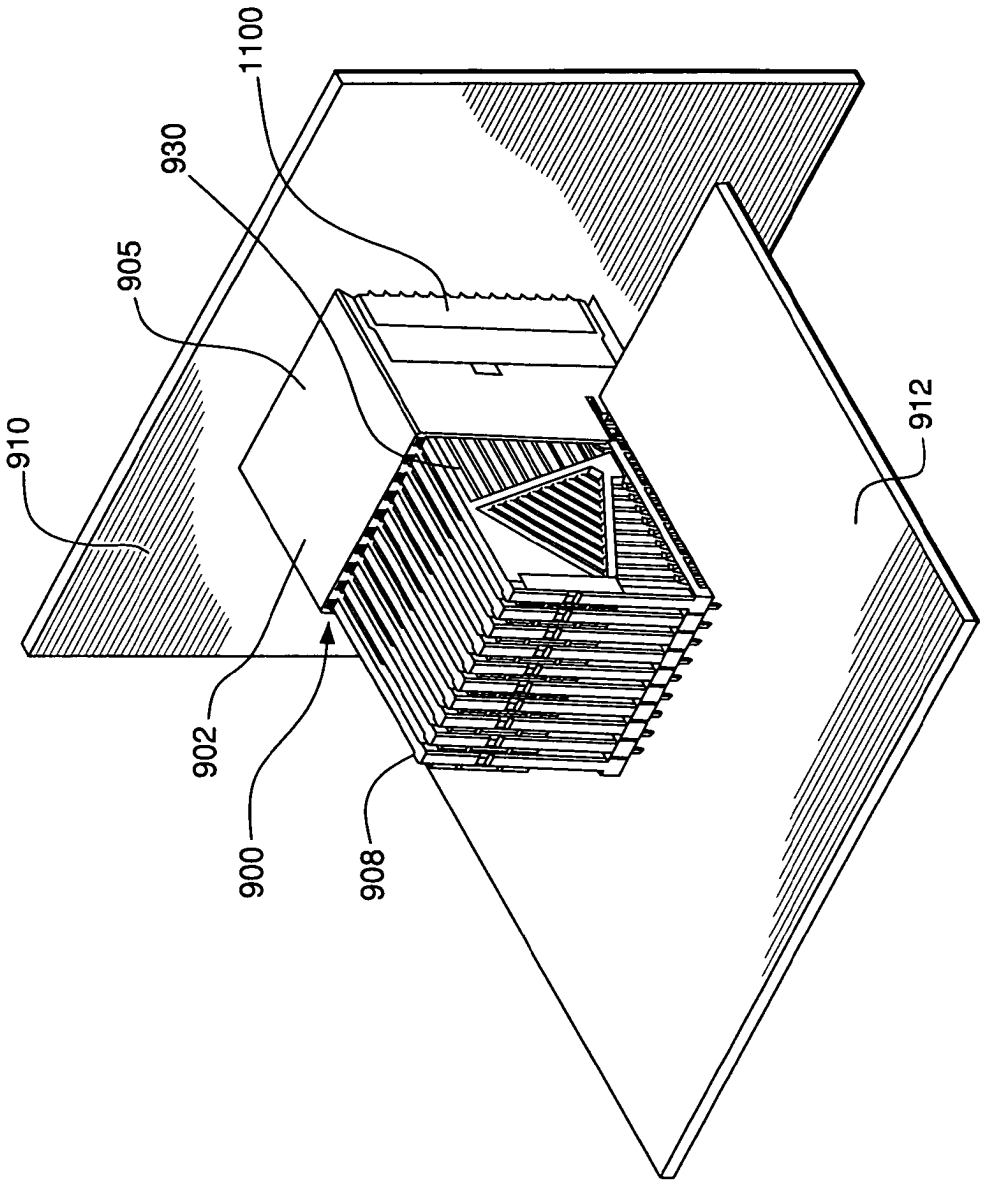


FIG. 16A

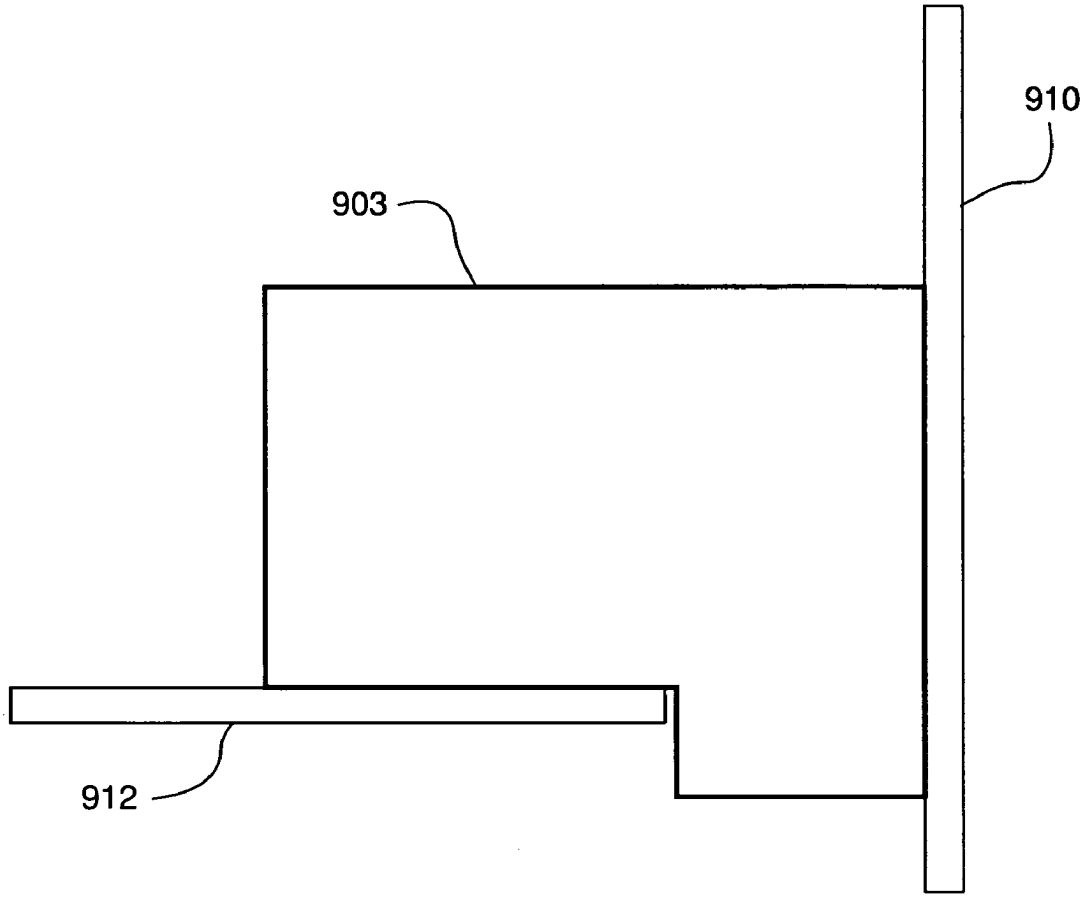


FIG. 16B

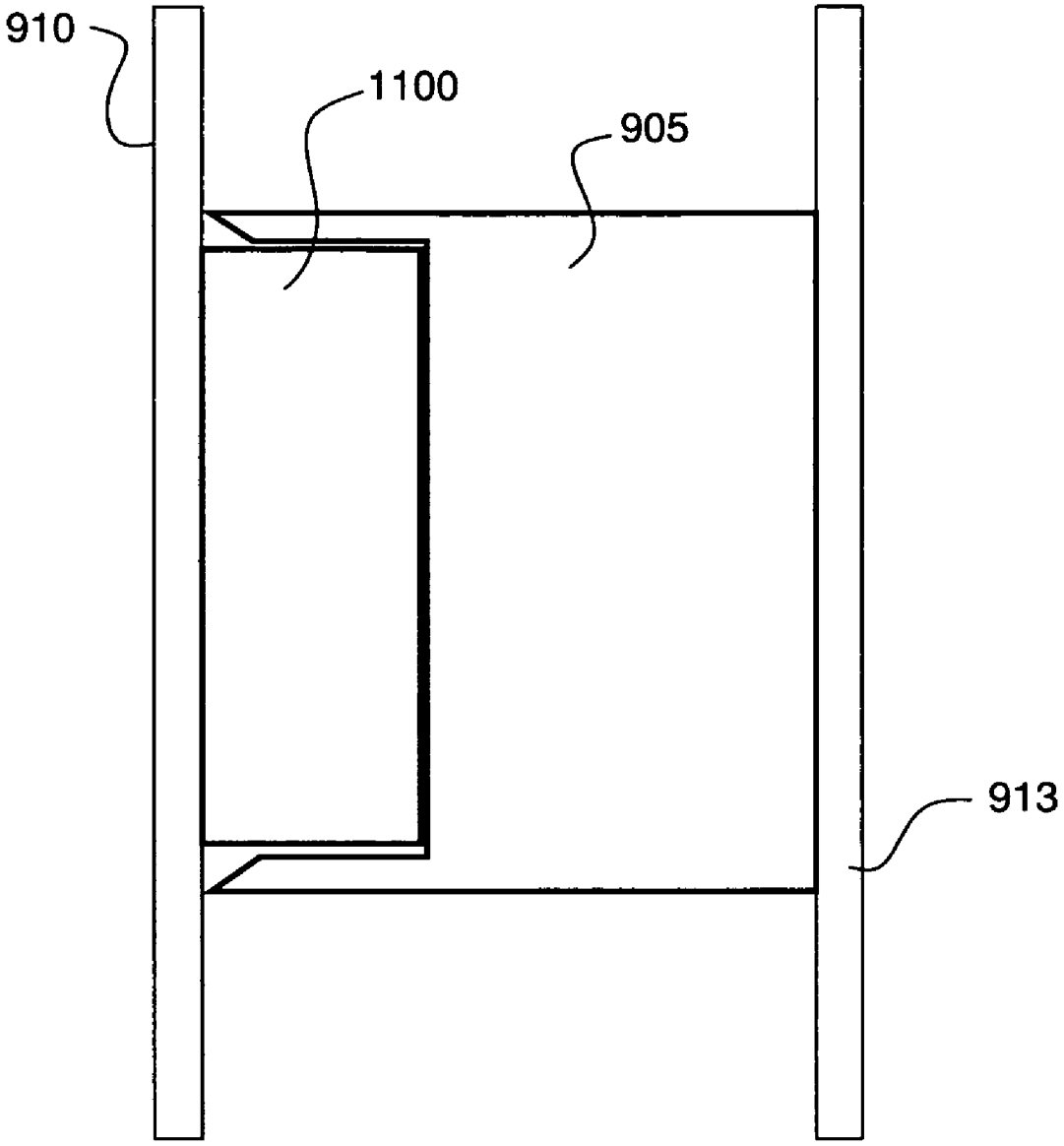


FIG. 16C

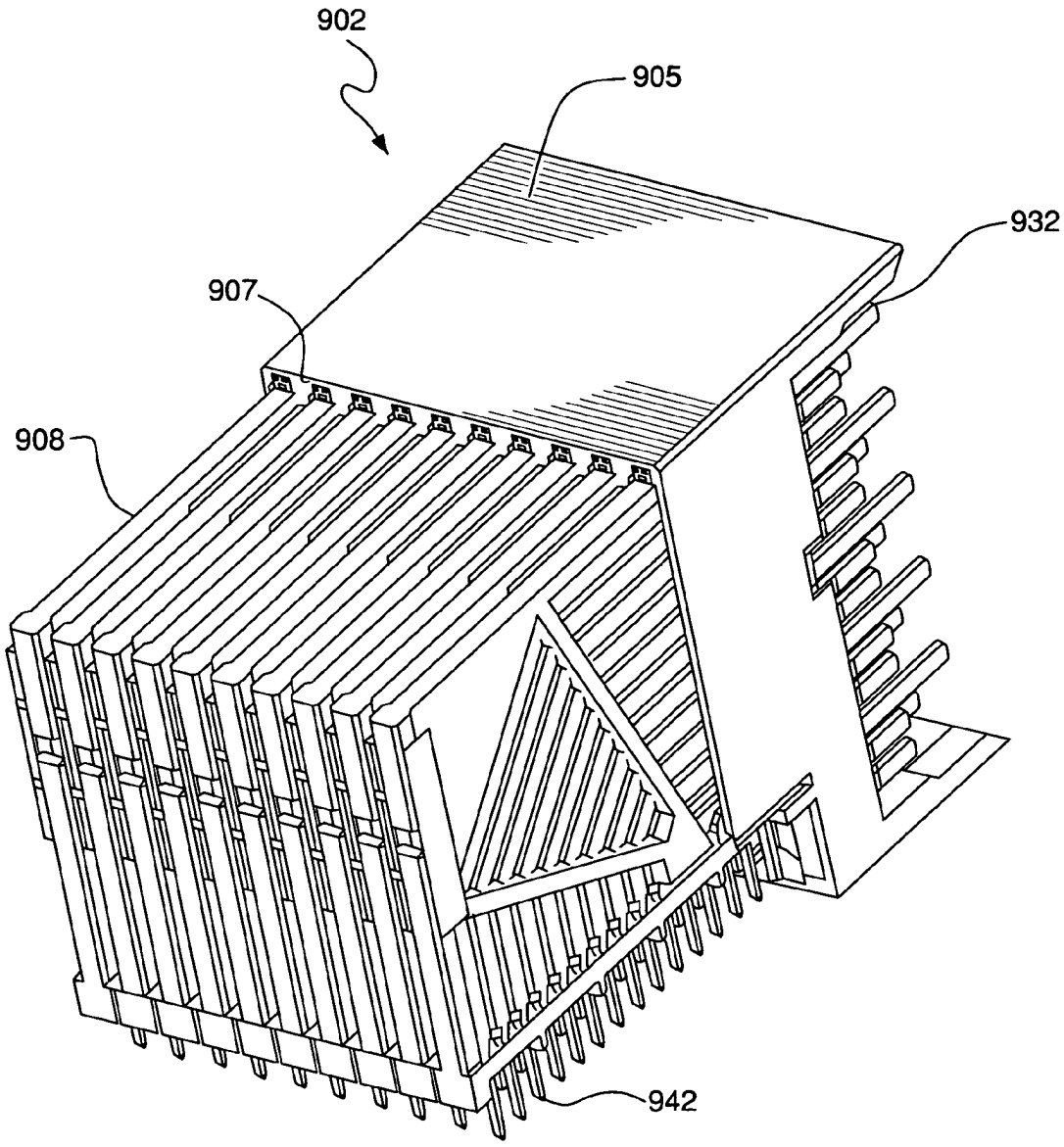


FIG. 17

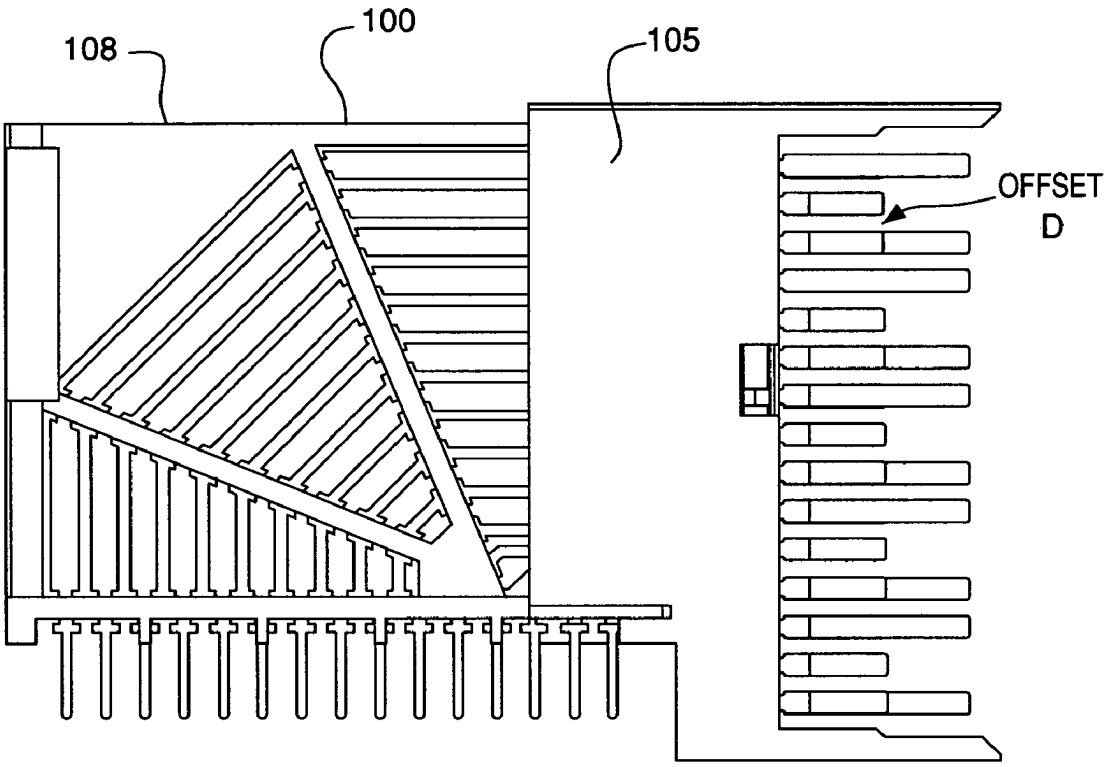


FIG. 18

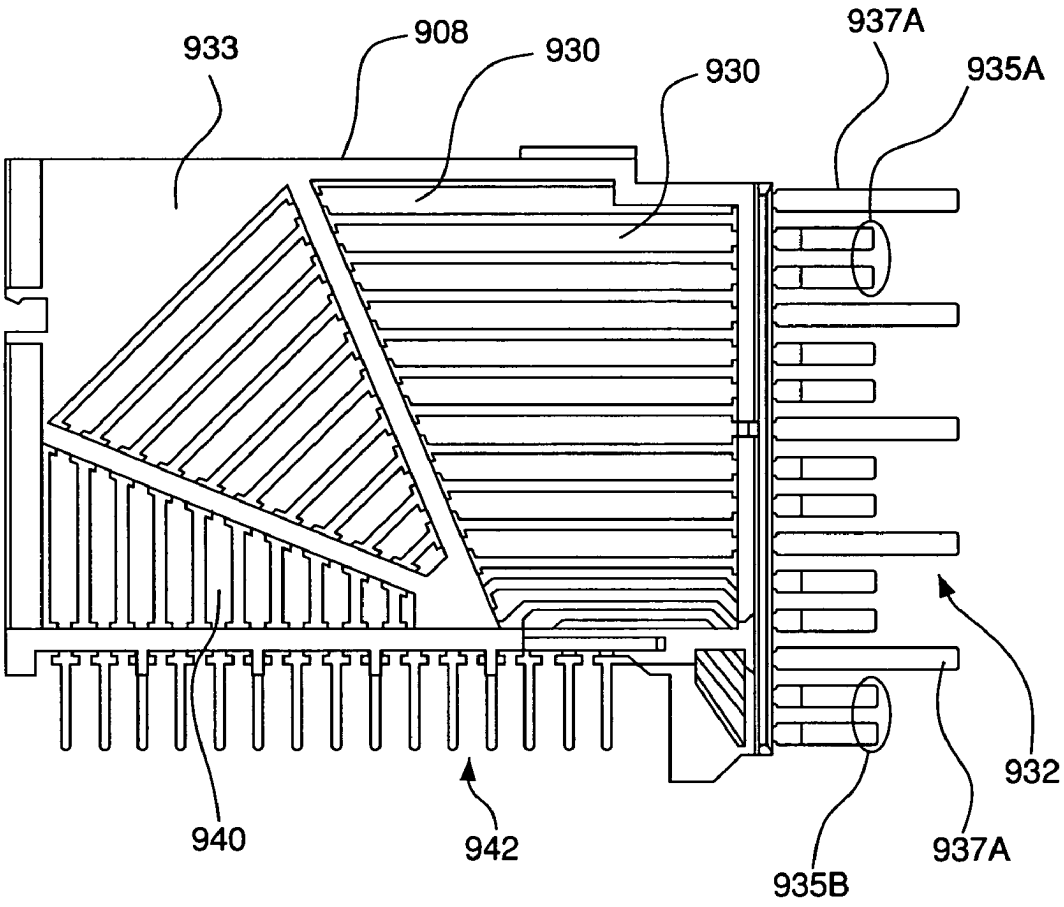


FIG. 19A

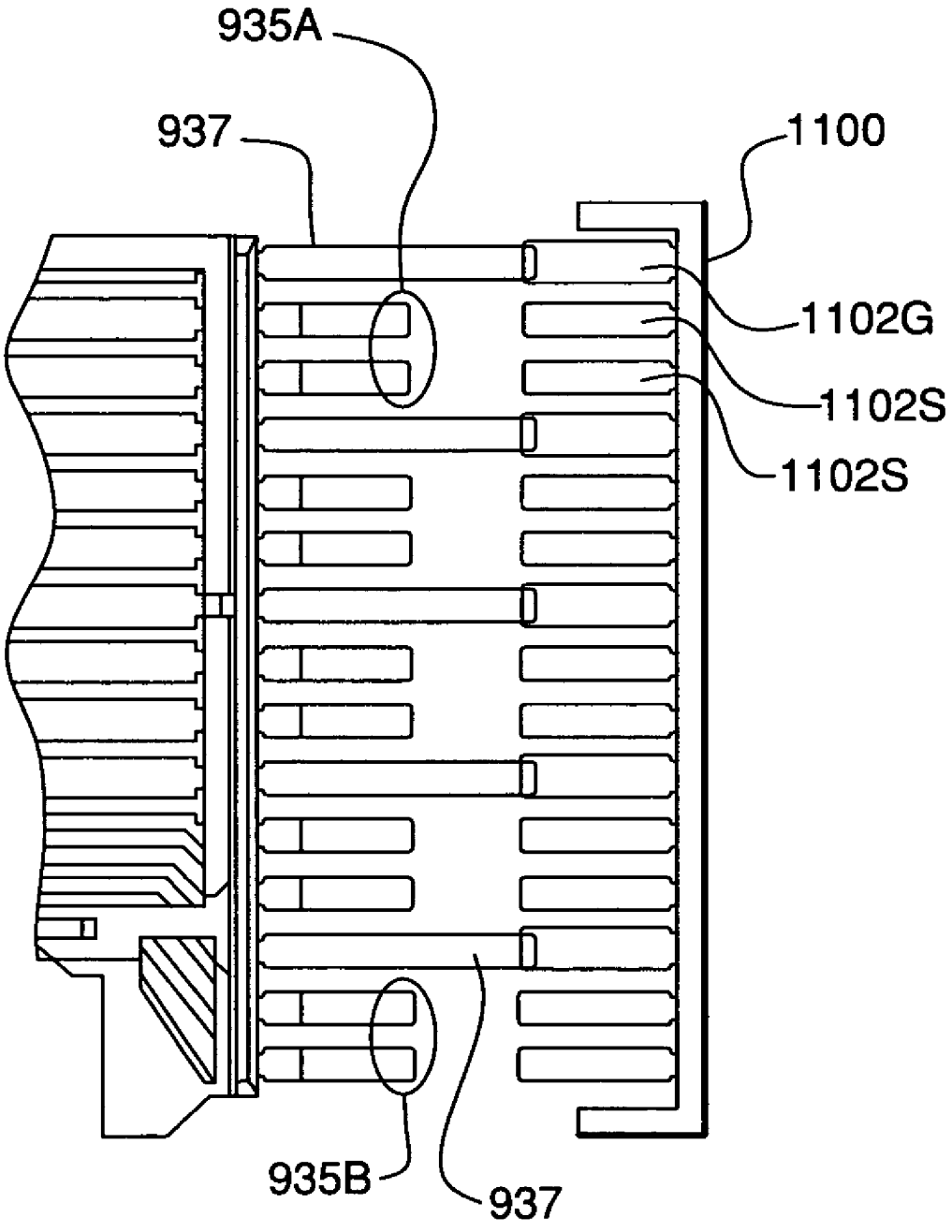


FIG. 19B

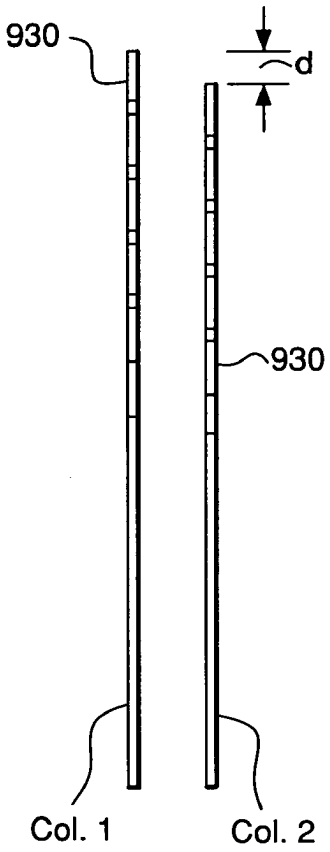


FIG. 20

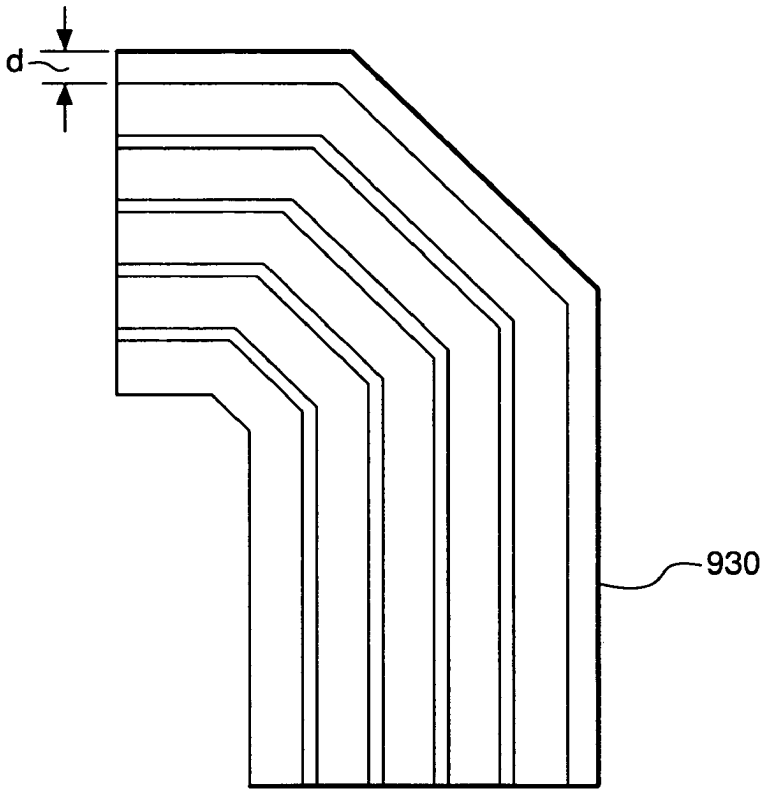


FIG. 21

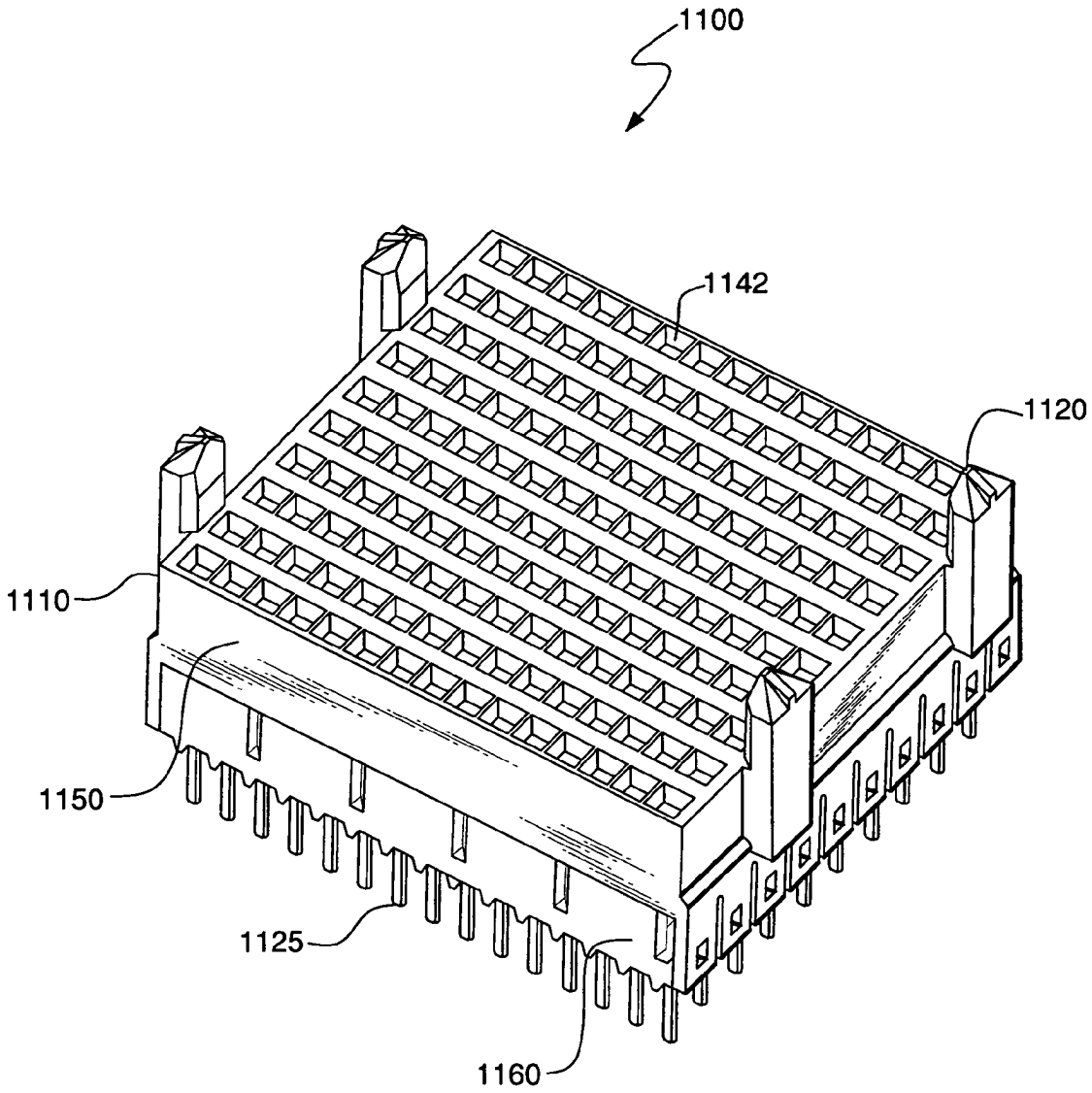


FIG. 22

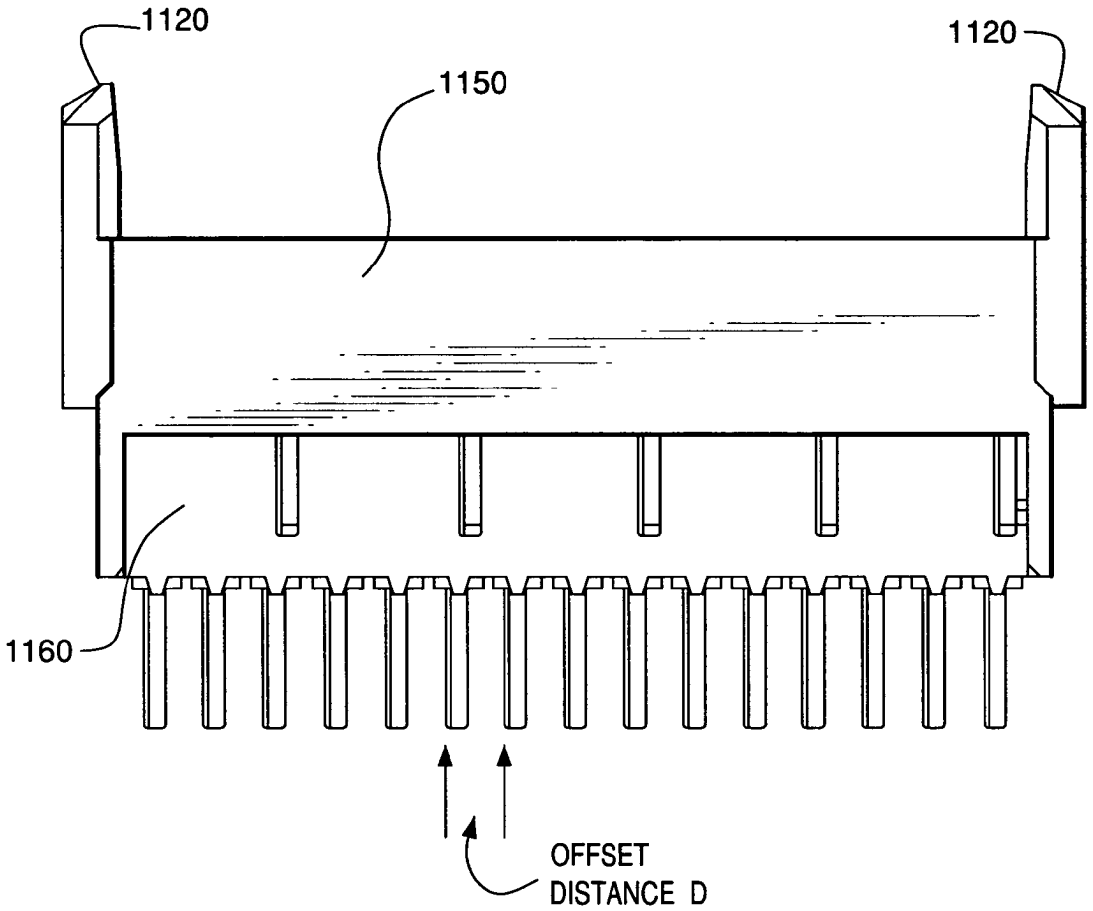


FIG. 23

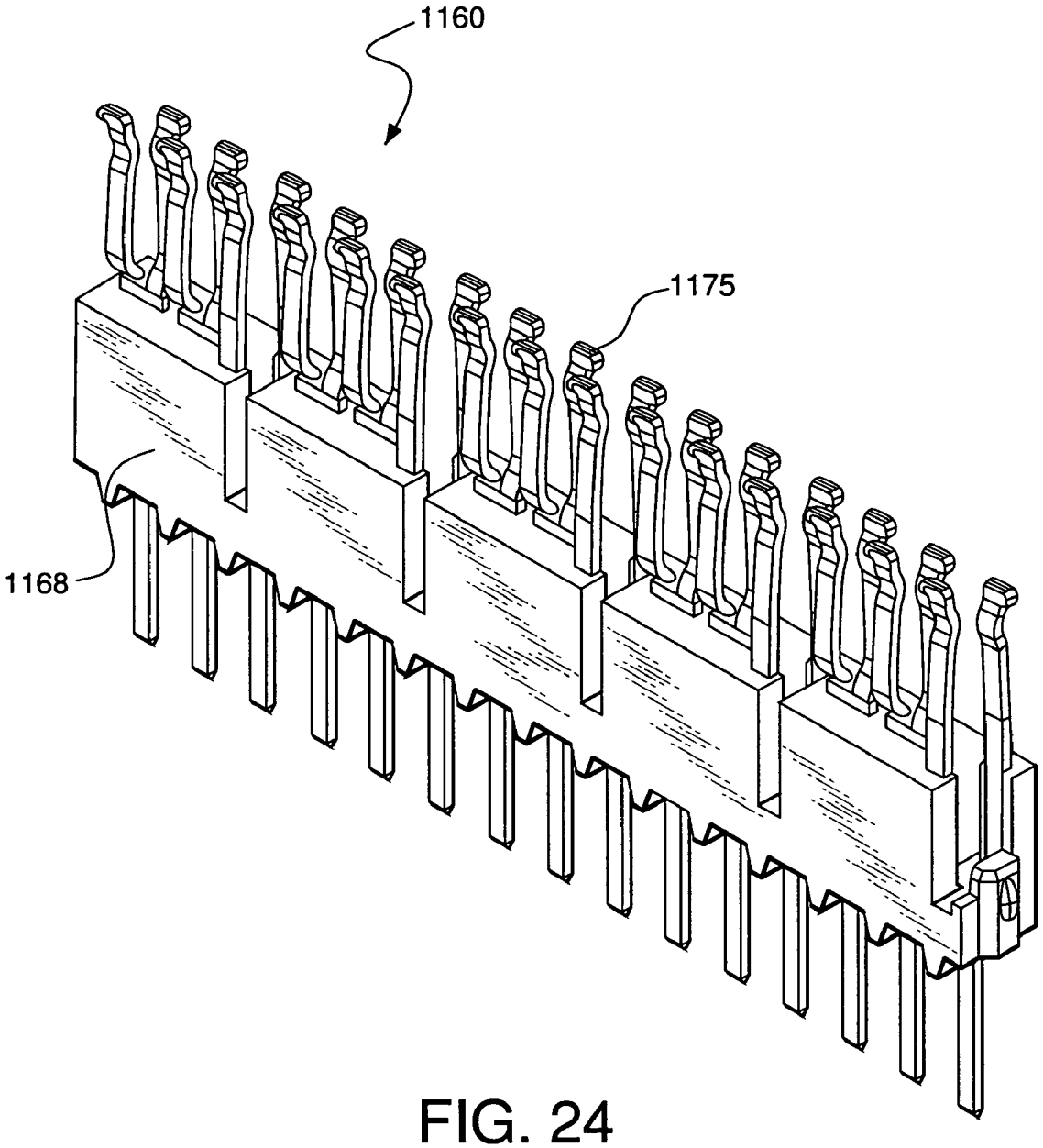


FIG. 24

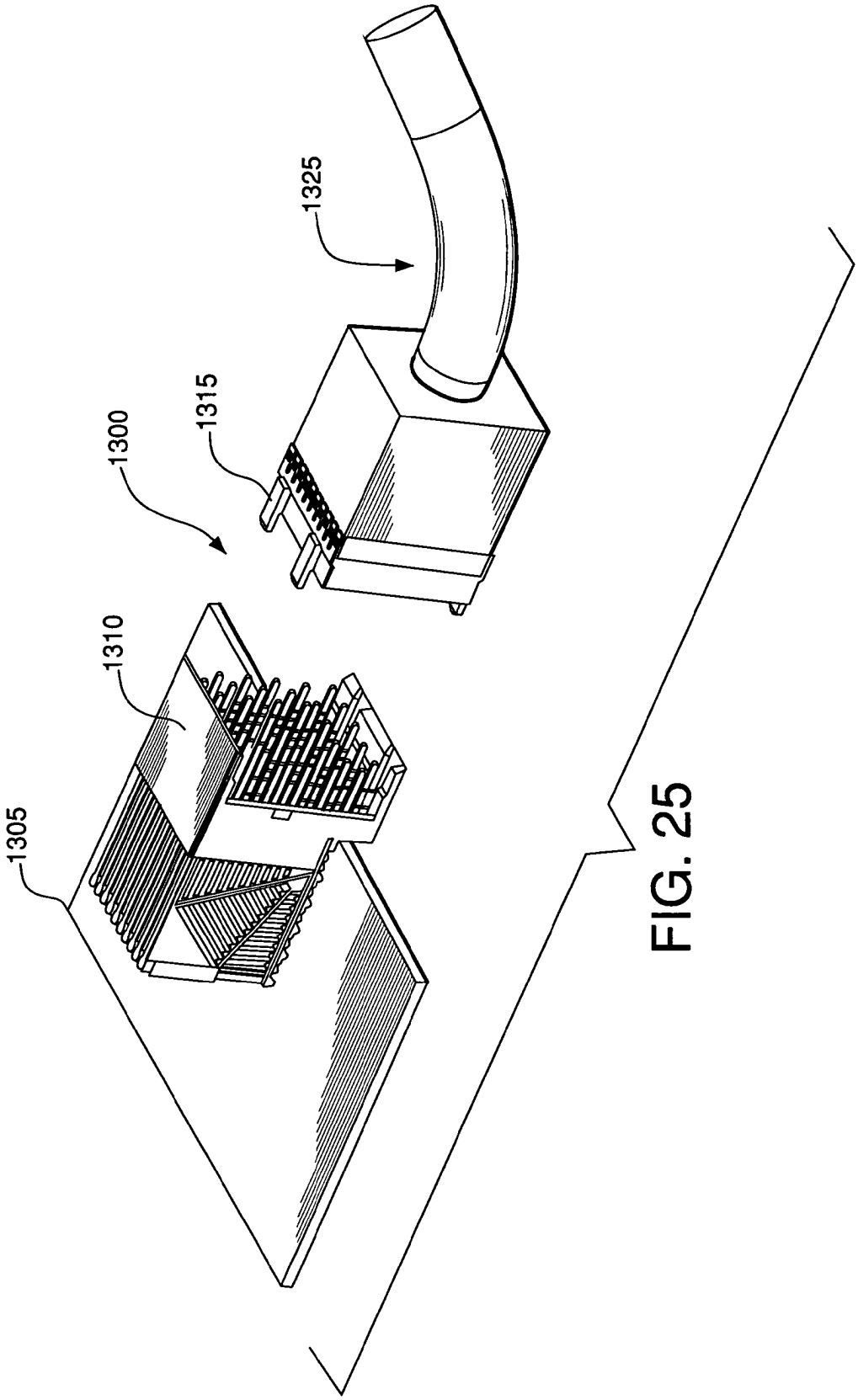


FIG. 25

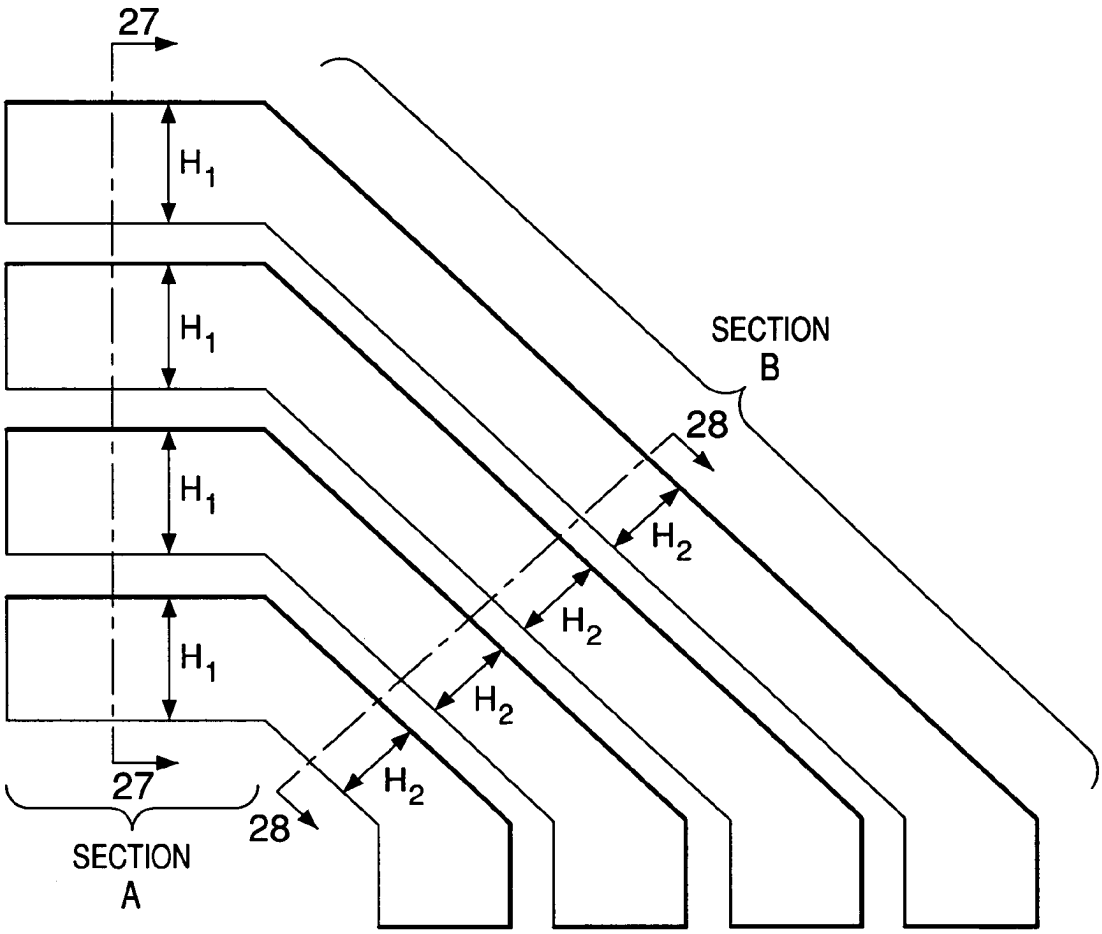


FIG. 26

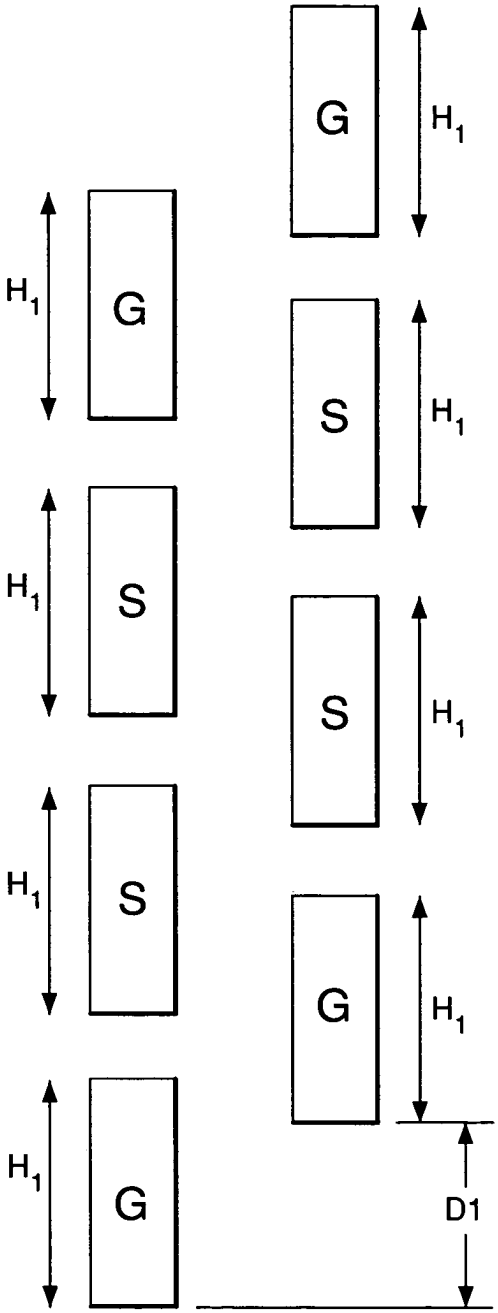

G
S
S
G
S
S
S
G
H1
H1
H1
H1
H1
H1
H1
H1
D1

FIG. 27

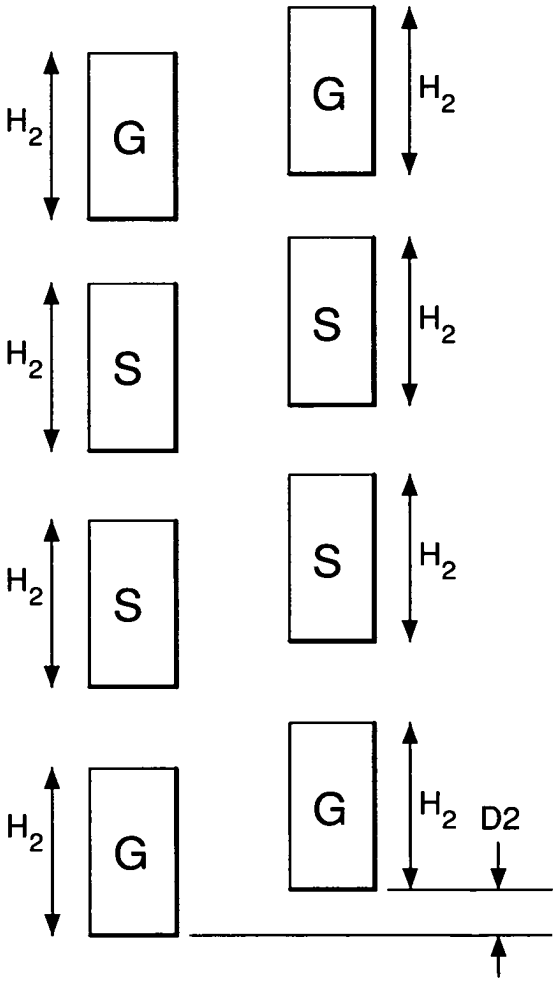

G
S
S
G
G
S
S
G
H2
H2
H2
H2
H2
H2
H2
H2
D2

FIG. 28

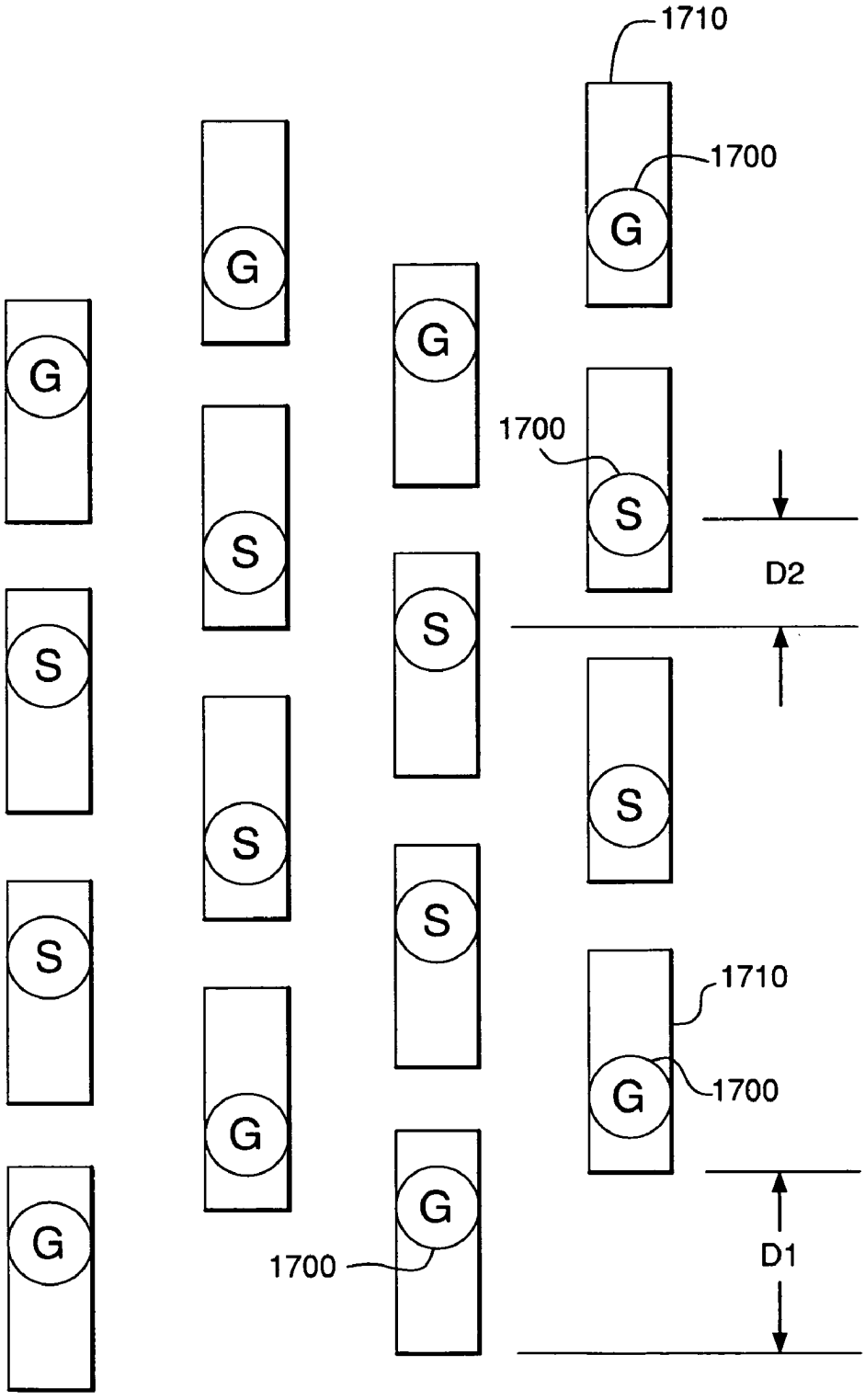


FIG. 29

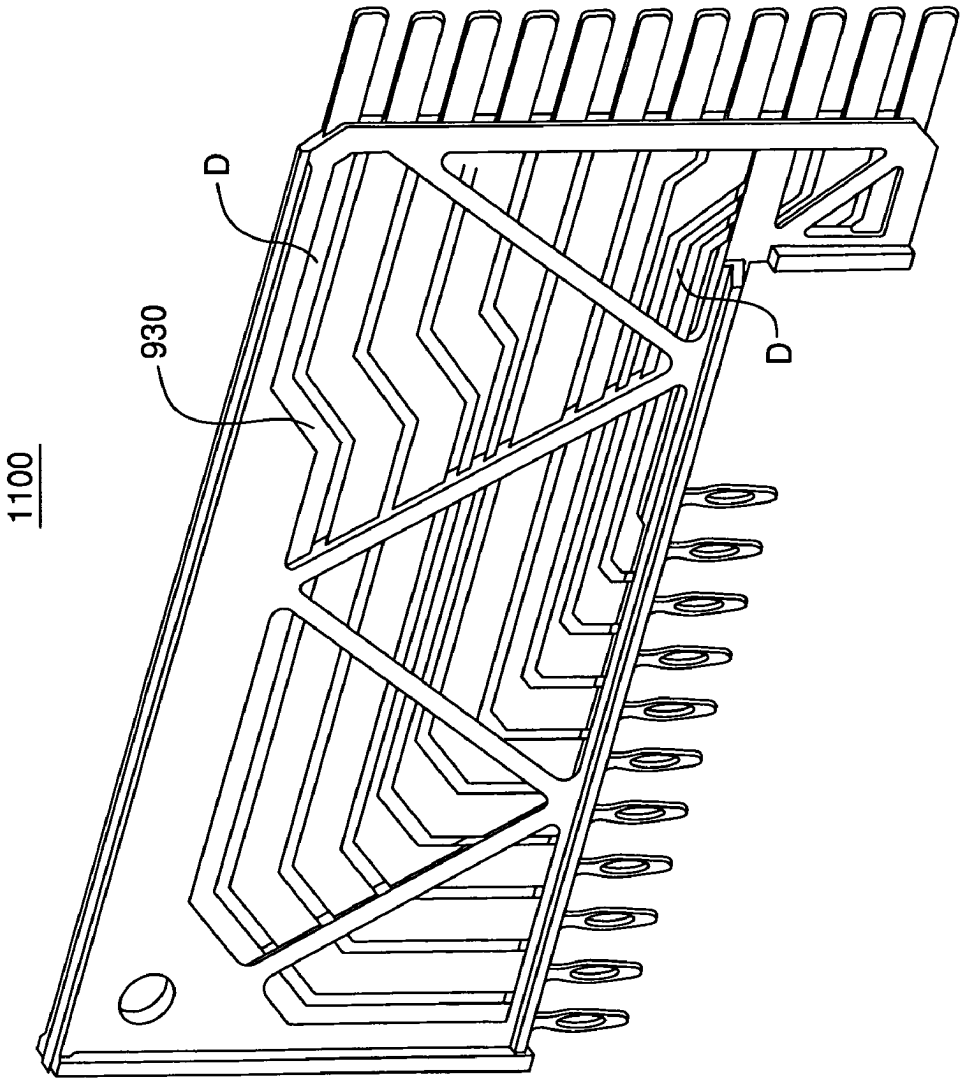


FIG. 30

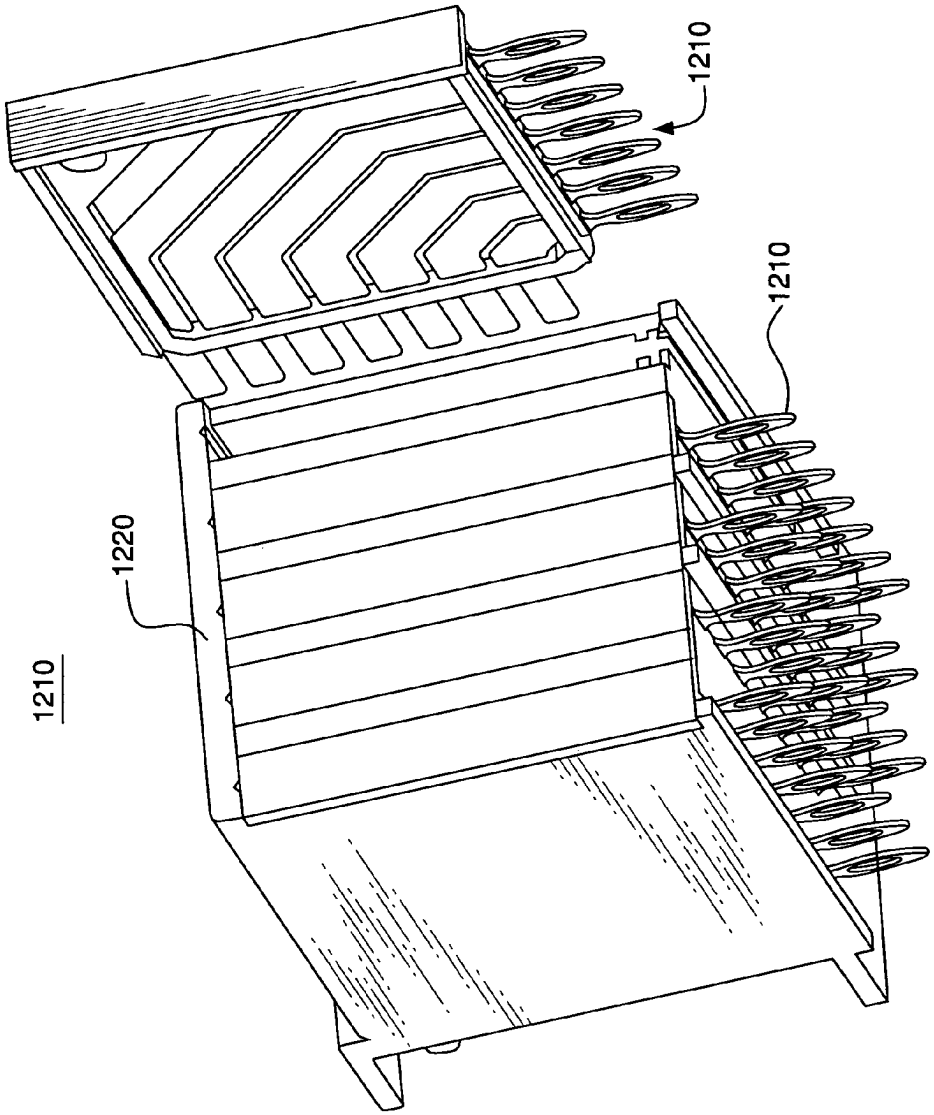


FIG. 31

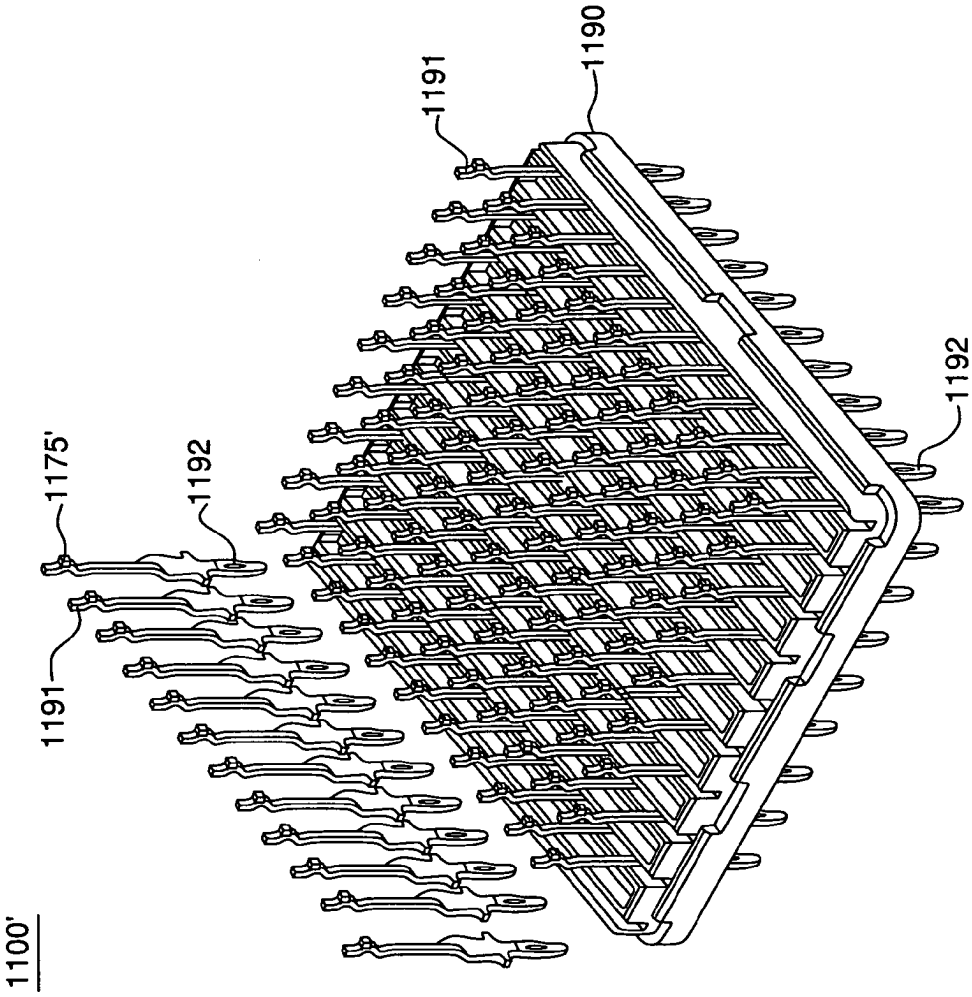


FIG. 32

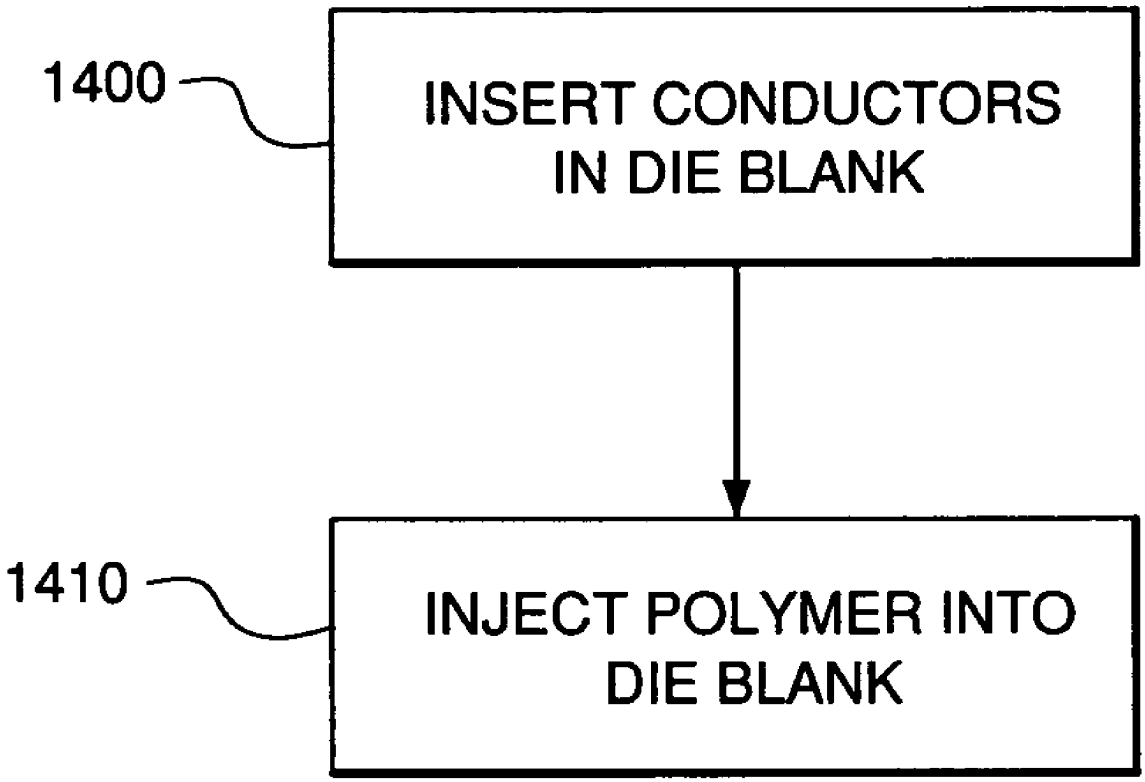

1400
INSERT CONDUCTORS IN DIE BLANK
1410
INJECT POLYMER INTO DIE BLANK

FIG. 33

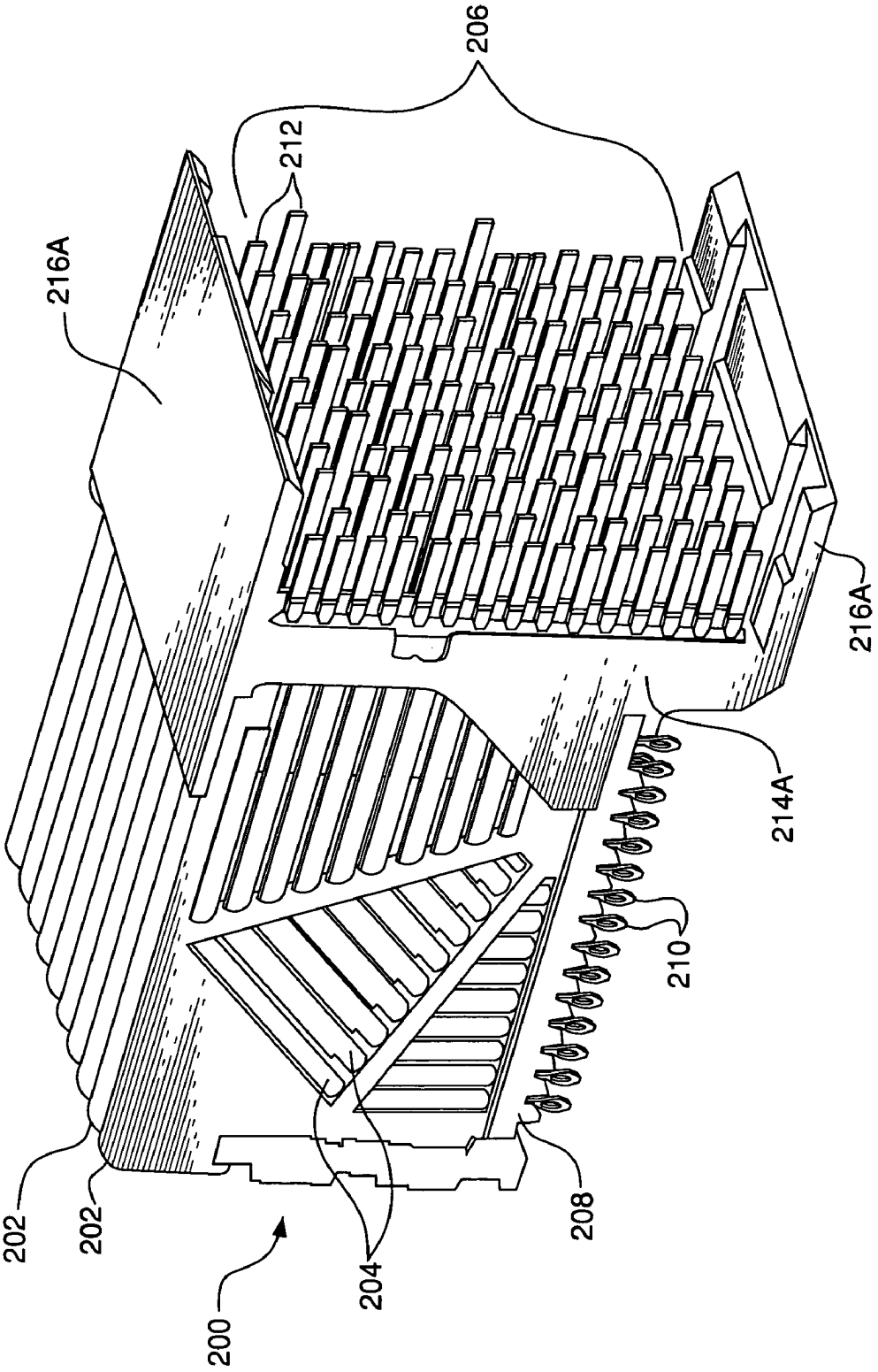


FIG. 34A

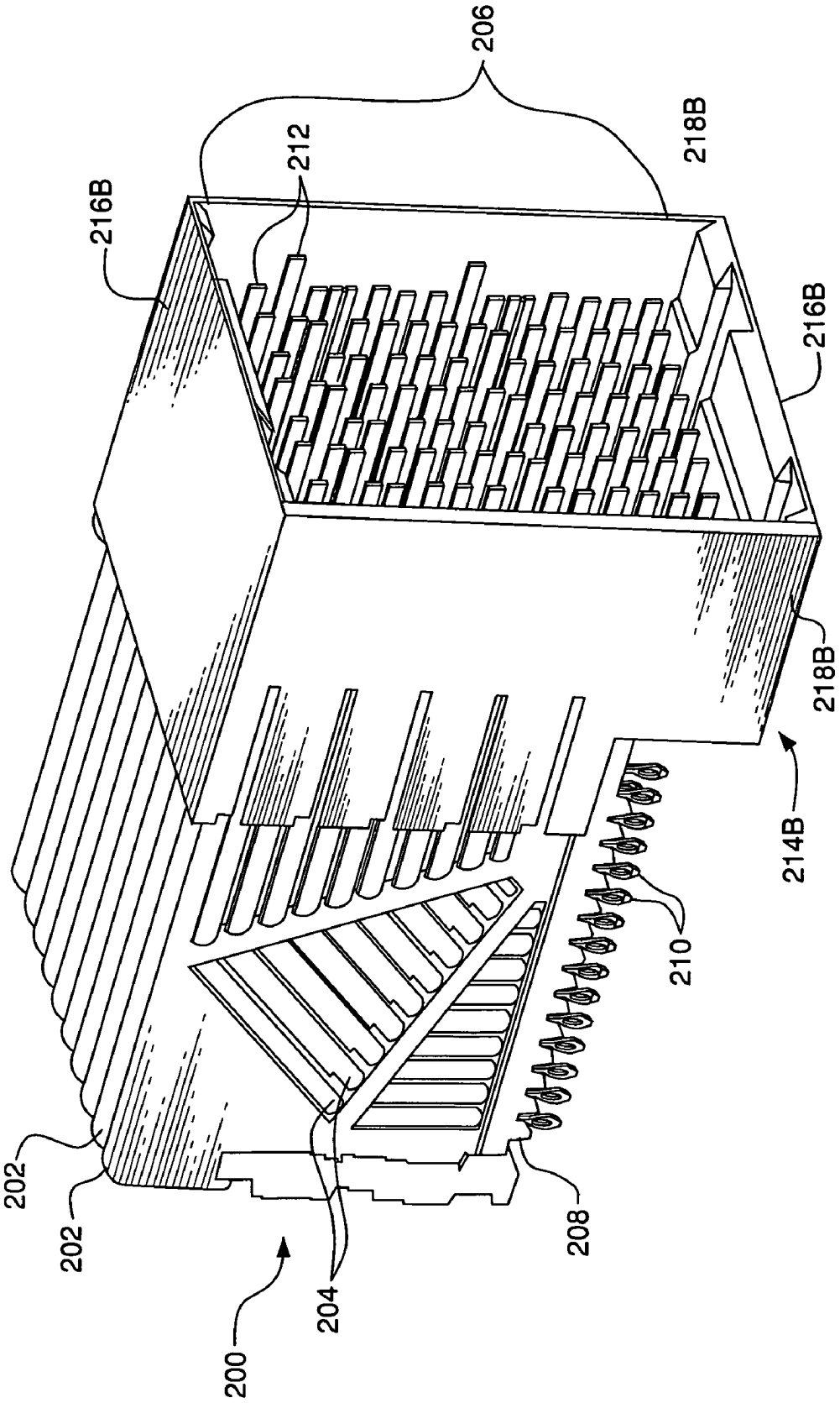


FIG. 34B

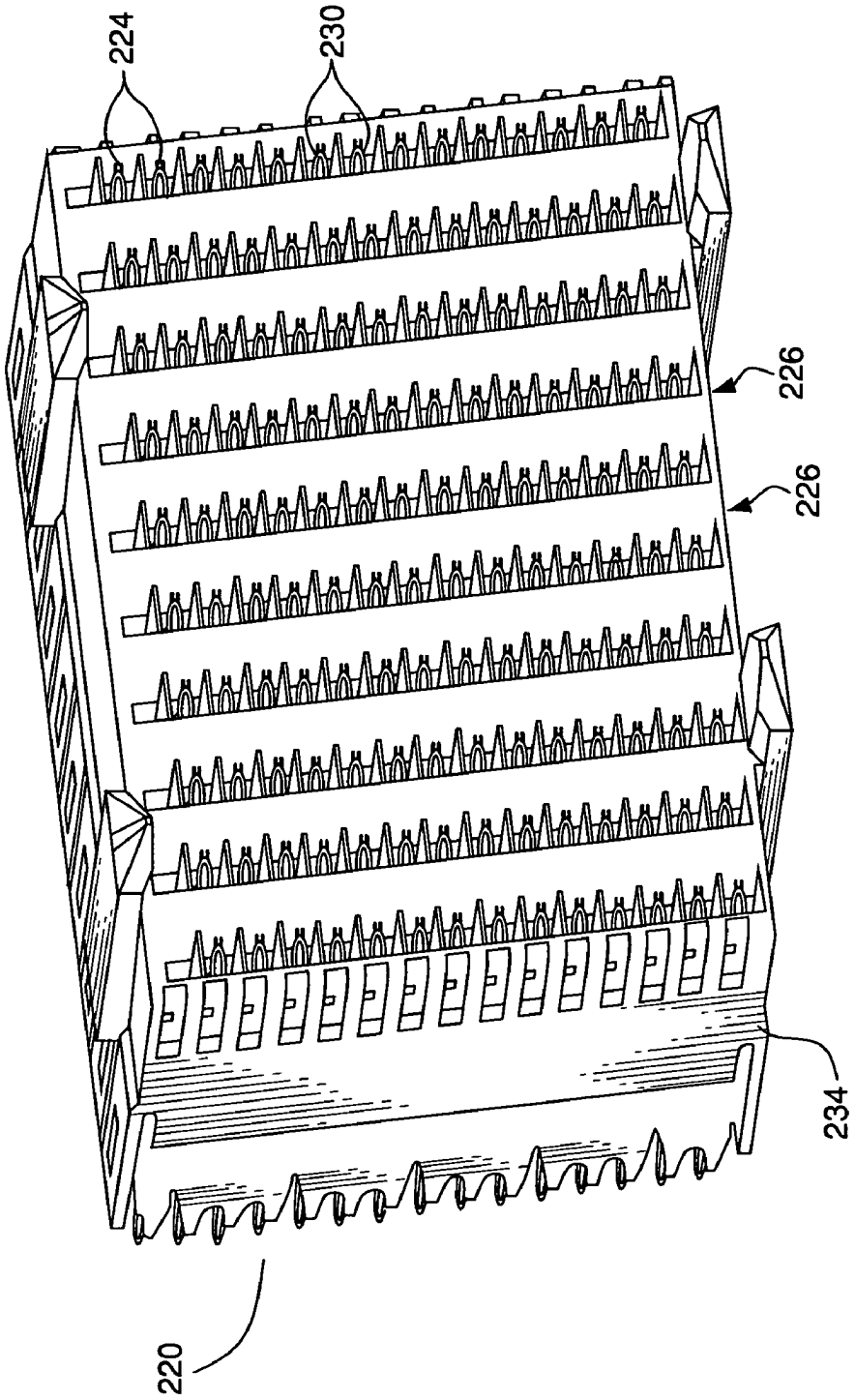


FIG. 35A

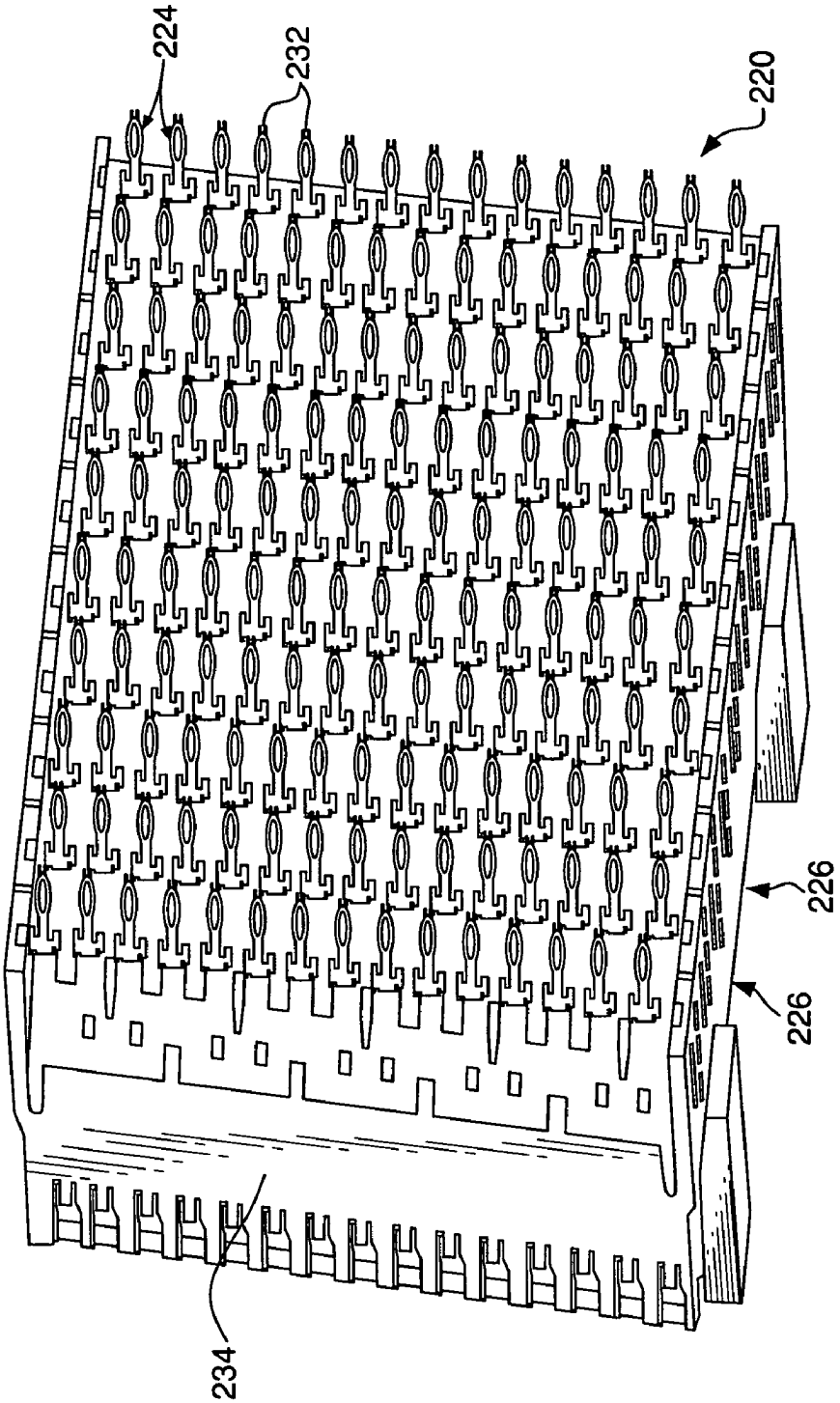


FIG. 35B

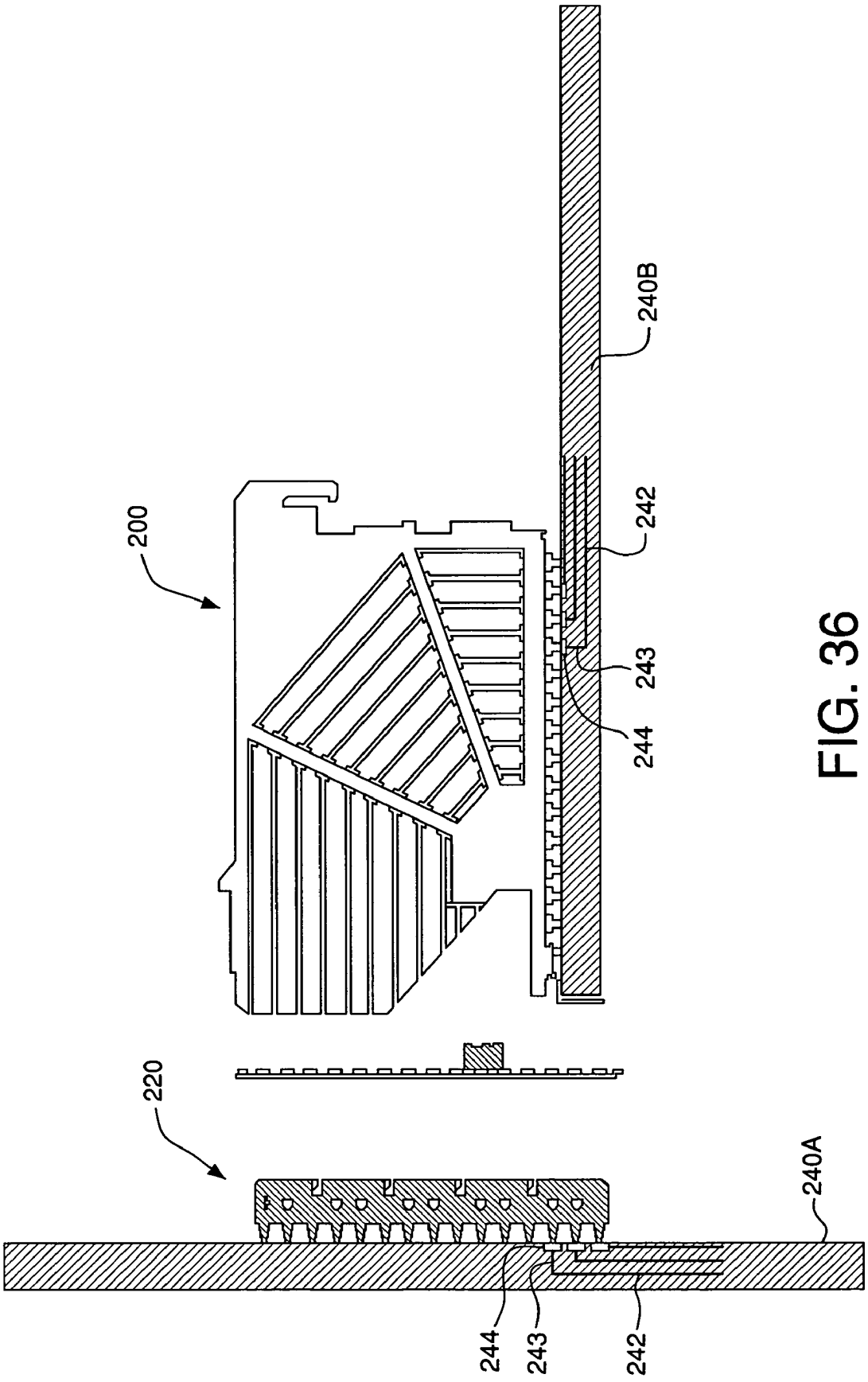


FIG. 36

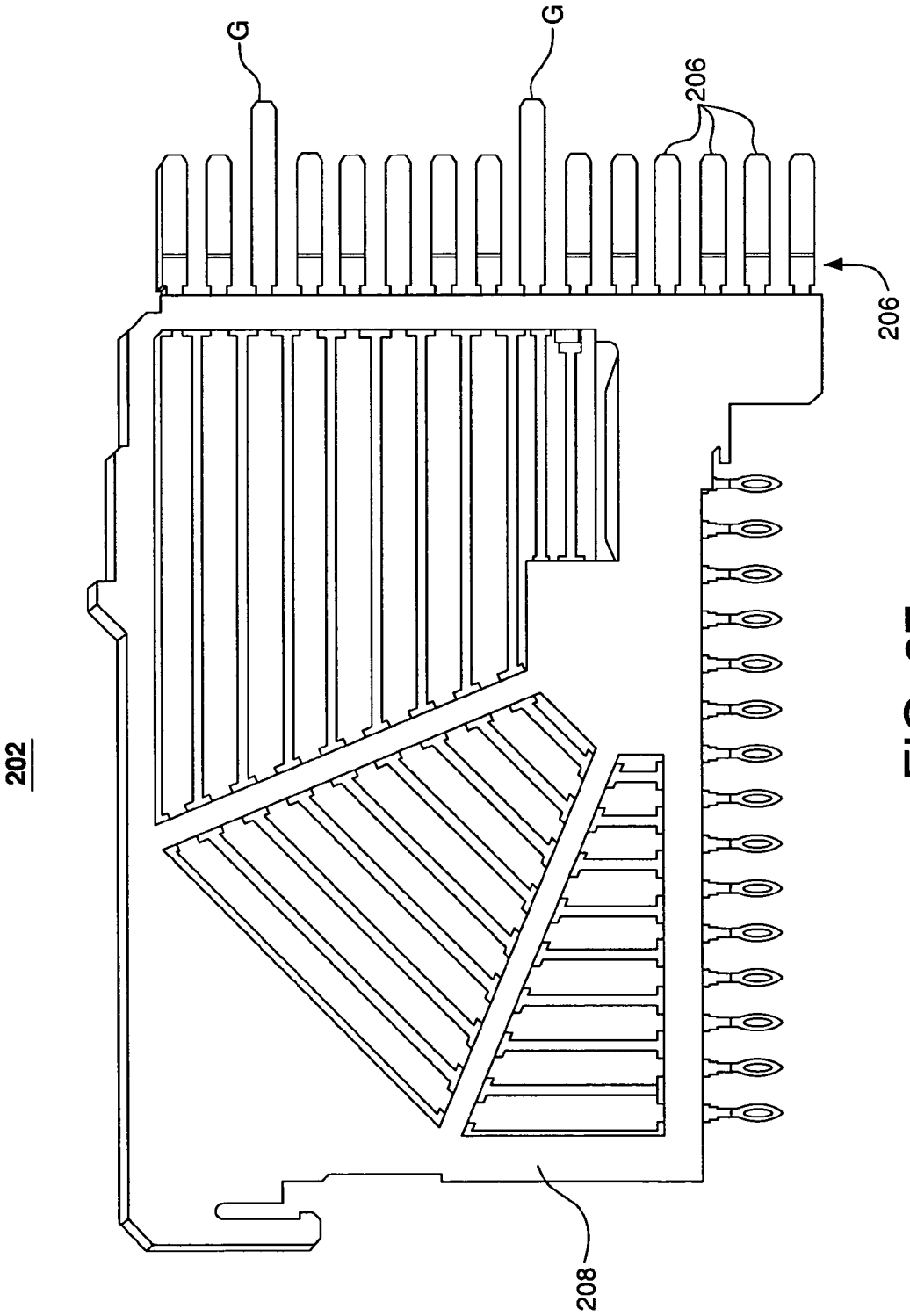


FIG. 37

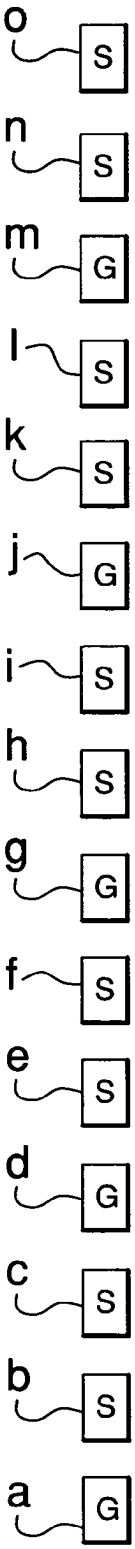


FIG. 38A

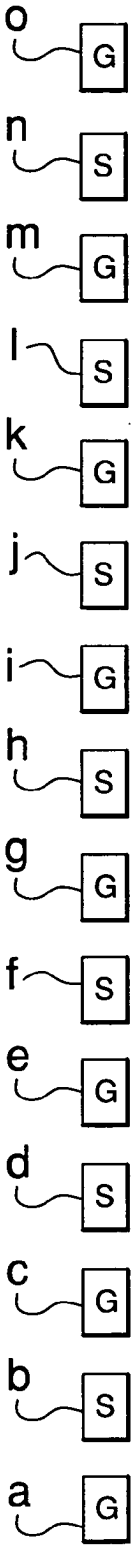


FIG. 38B

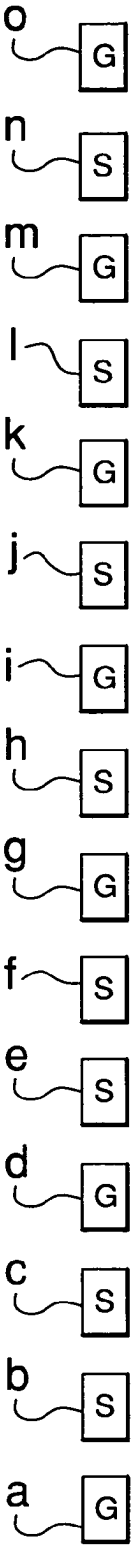


FIG. 38C

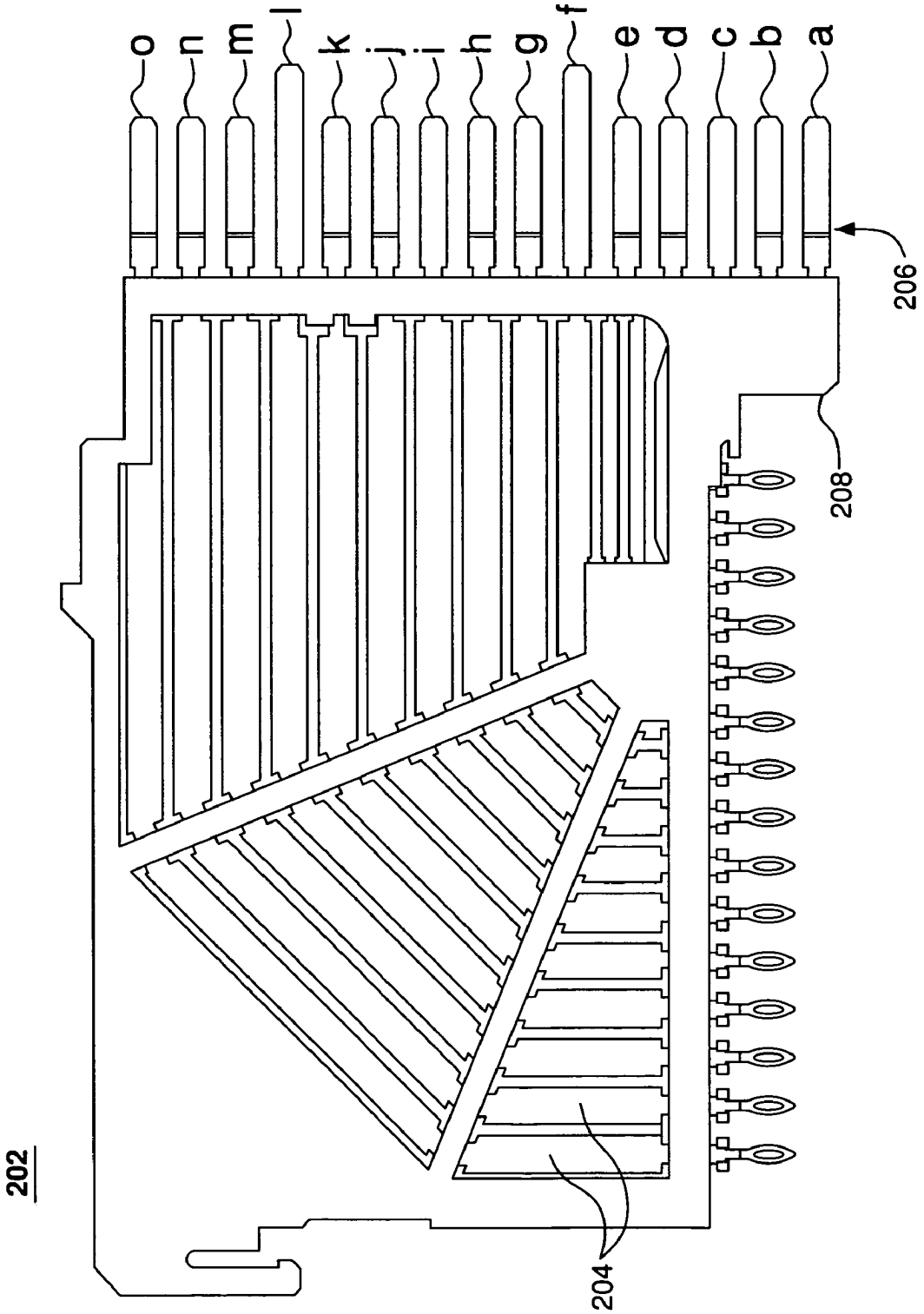


FIG. 39

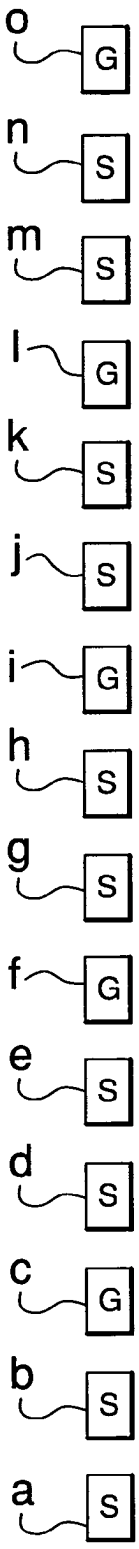


FIG. 40A

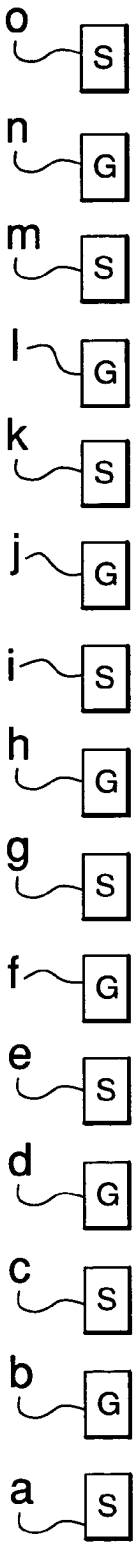


FIG. 40B

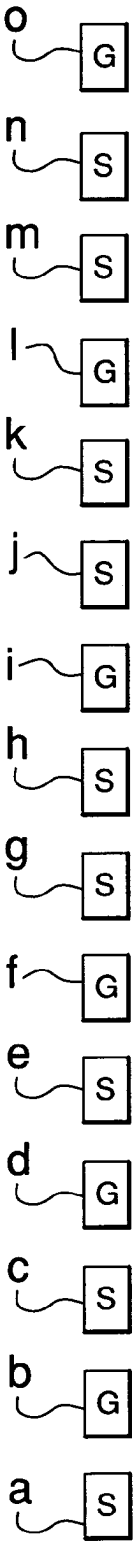


FIG. 40C

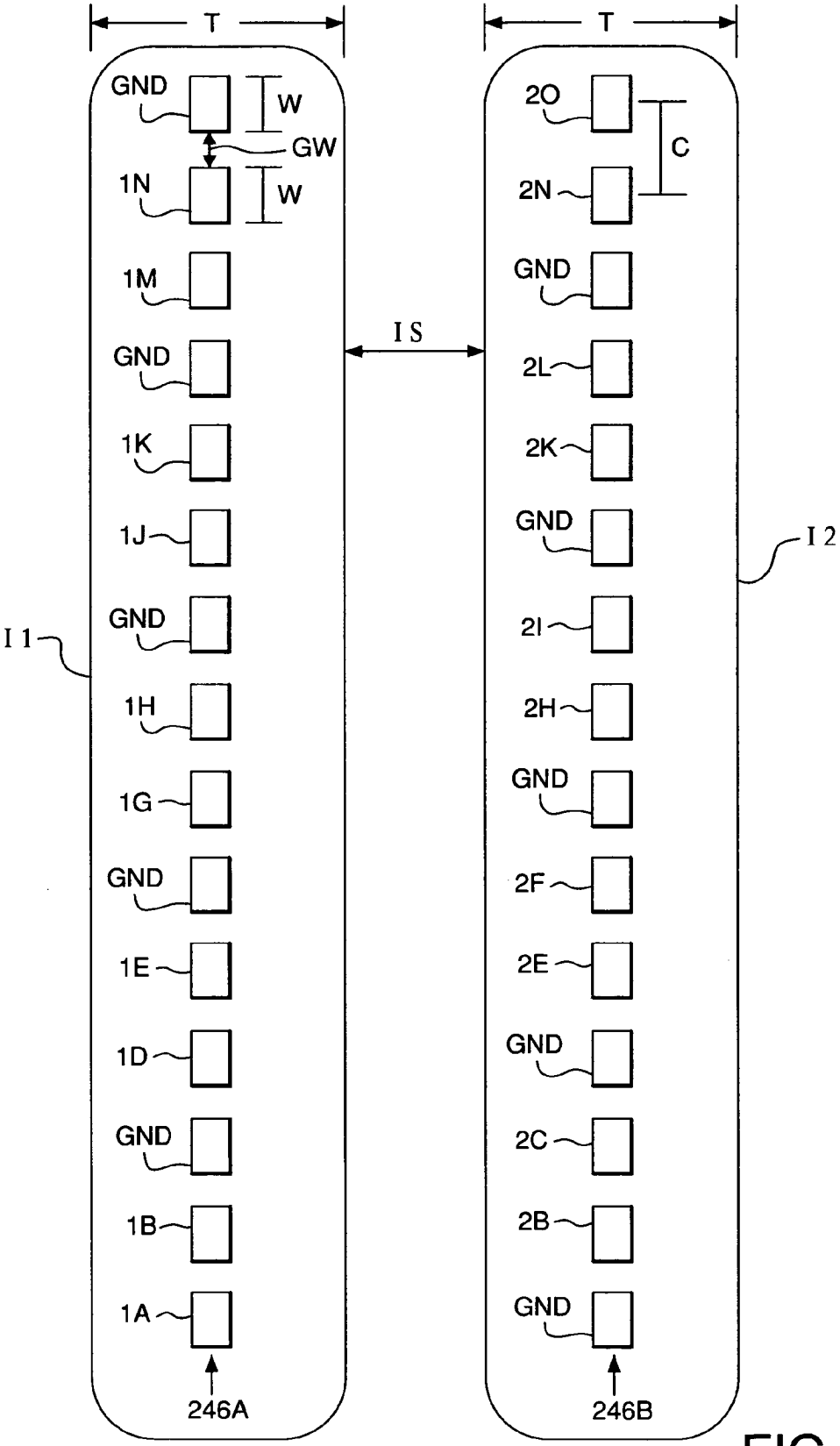

T
T
GND
W
GW
1N
W
1M
GND
1K
1J
GND
1H
1G
GND
1E
1D
GND
1B
1A
246A
I S
2O
C
2N
GND
2L
2K
GND
2I
2H
GND
2F
2E
GND
2C
2B
GND
246B
I 1
I 2

FIG. 41

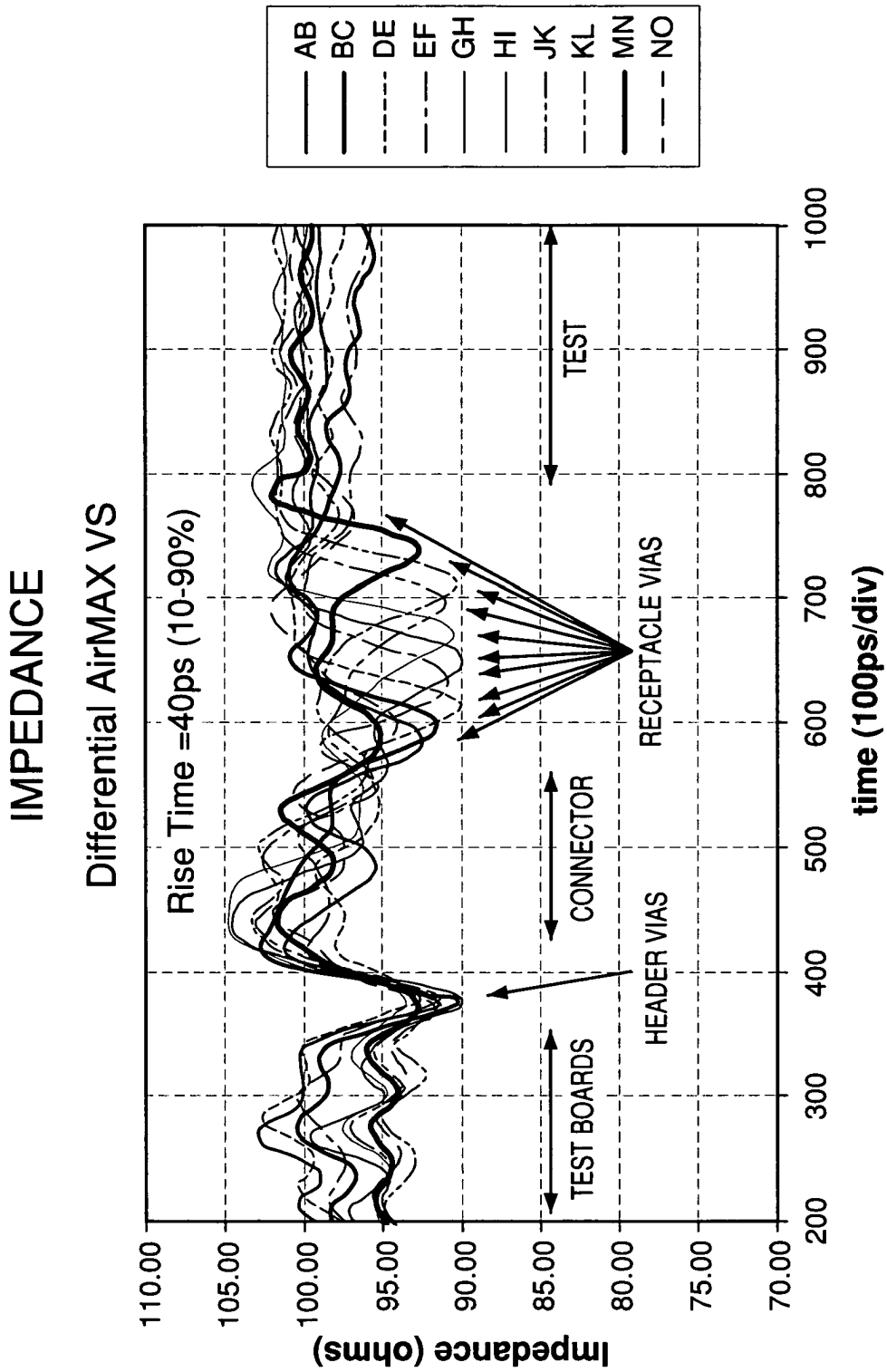

IMPEDANCE
Differential AirMAX VS
Rise Time =40ps (10-90%)
AB
BC
DE
EF
GH
HI
JK
KL
MN
NO
TEST
RECEPTACLE VIAS
CONNECTOR
HEADER VIAS
TEST BOARDS
impedance (ohms)
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
200
300
400
500
600
700
800
900
1000
time (100ps/div)

FIG. 42A

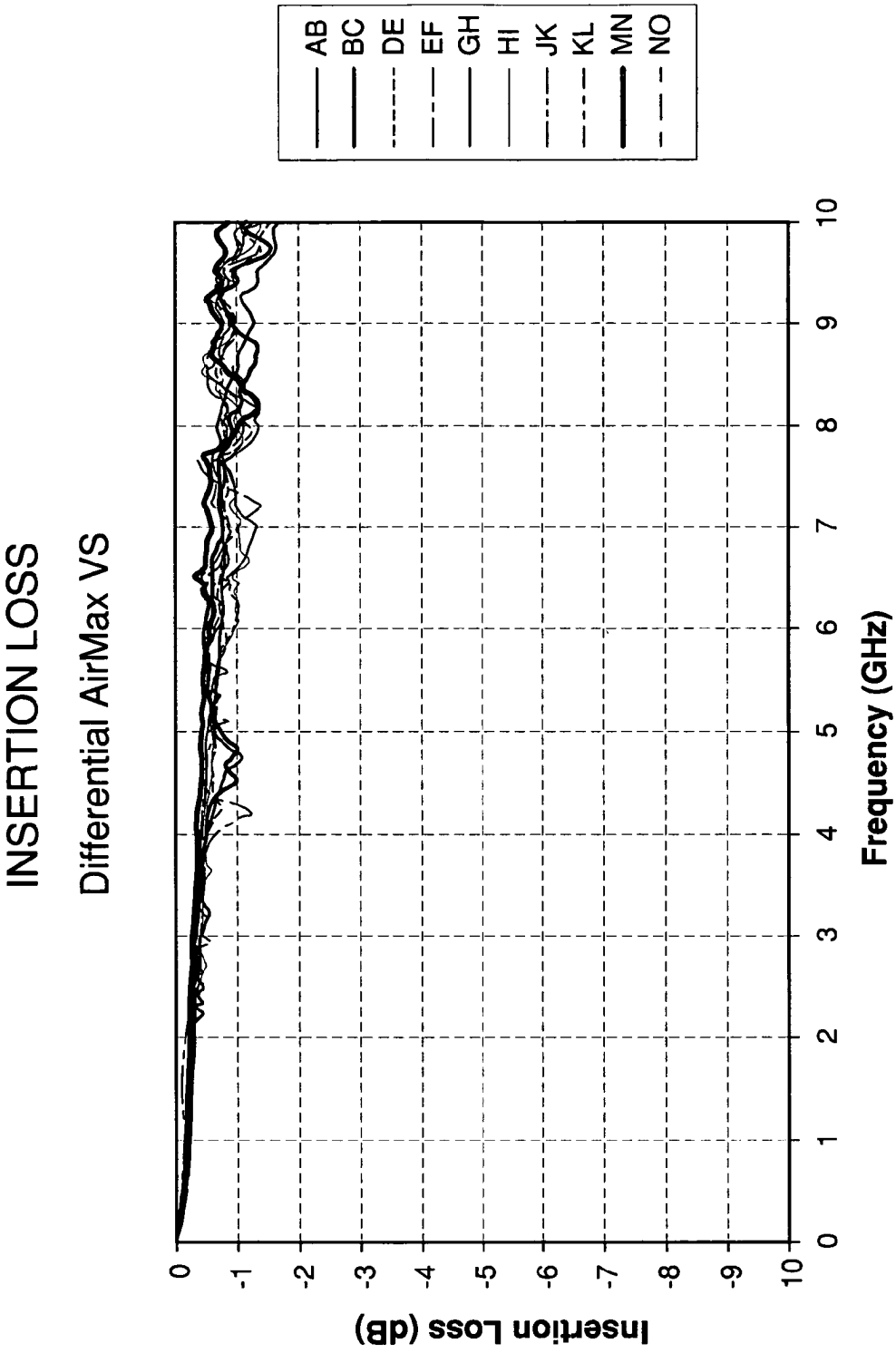

INSERTION LOSS
Differential AirMax VS
AB
BC
DE
EF
GH
HI
JK
KL
MN
NO
Insertion Loss (dB)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Frequency (GHz)
0
1
2
3
4
5
6
7
8
9
10

FIG. 42B

CROSSTALK

Worst-Case Multi-Active Near-End Crosstalk

	AB	BC	DE	EF	GH	HI	JK	KL	MN	NO
40ps (10-90%)	1.9	2.4	2.4	2.3	2.5	2.2	2.4	2.1	2.6	1.7
100ps (10-90%)	1.4	1.8	1.7	1.8	1.9	1.7	2.0	1.7	1.8	1.0

FIG. 42C

Worst-Case Multi-Active Far-End Crosstalk

	AB	BC	DE	EF	GH	HI	JK	KL	MN	NO
40ps (10-90%)	2.7	1.8	5.0	3.4	4.2	3.2	4.1	2.9	2.4	1.1
100ps (10-90%)	1.3	0.8	2.2	1.5	1.9	1.4	1.8	1.3	1.1	0.5

FIG. 42D

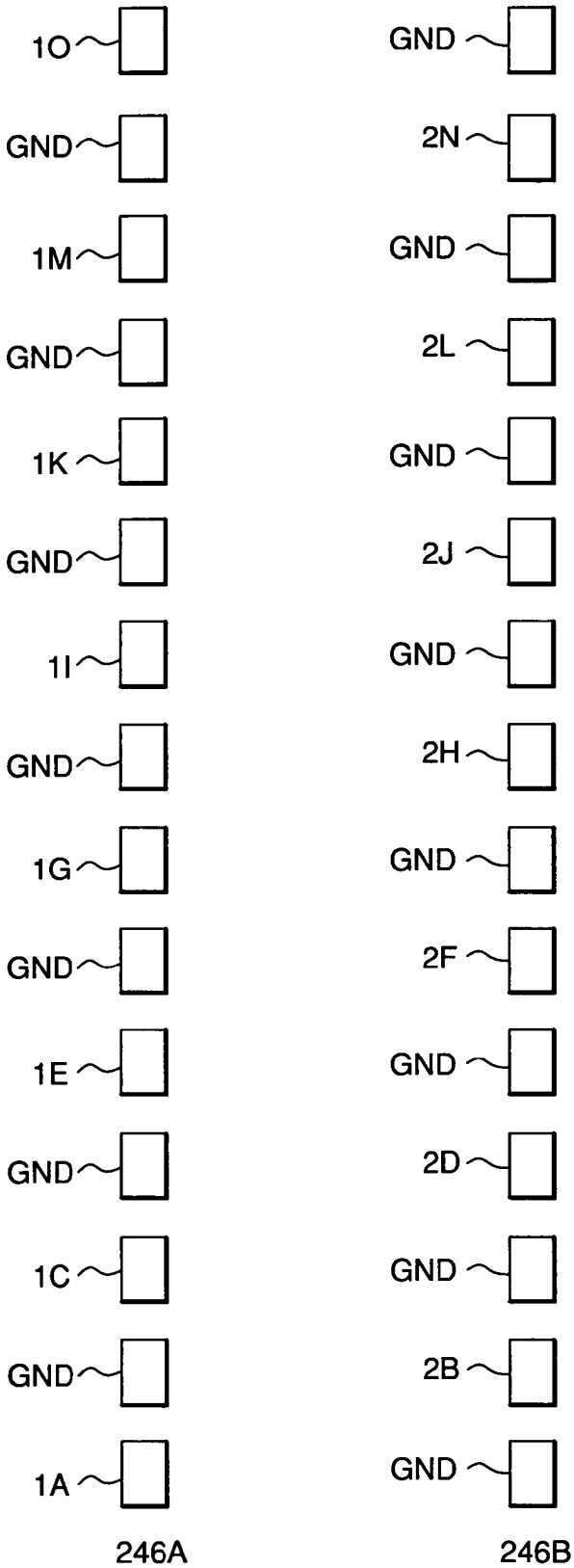

1O
GND
1M
GND
1K
GND
1I
GND
1G
GND
1E
GND
1C
GND
1A
246A
GND
2N
GND
2L
GND
2J
GND
2H
GND
2F
GND
2D
GND
2B
GND
246B

FIG.43

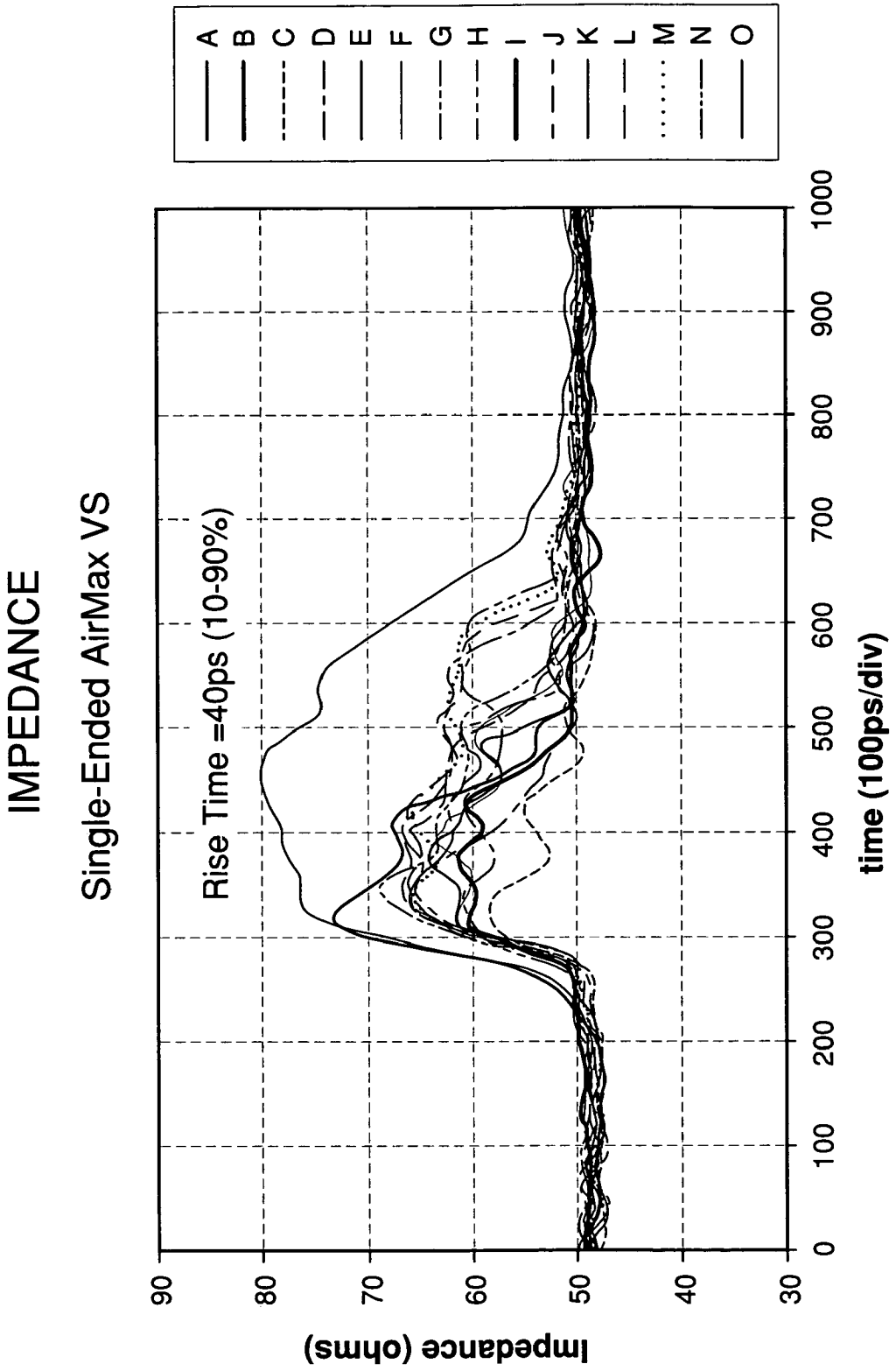

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
IMPEDANCE
Single-Ended AirMax VS
Rise Time =40ps (10-90%)
impedance (ohms)
90
80
70
60
50
40
30
time (100ps/div)
0
100
200
300
400
500
600
700
800
900
1000

FIG. 44A

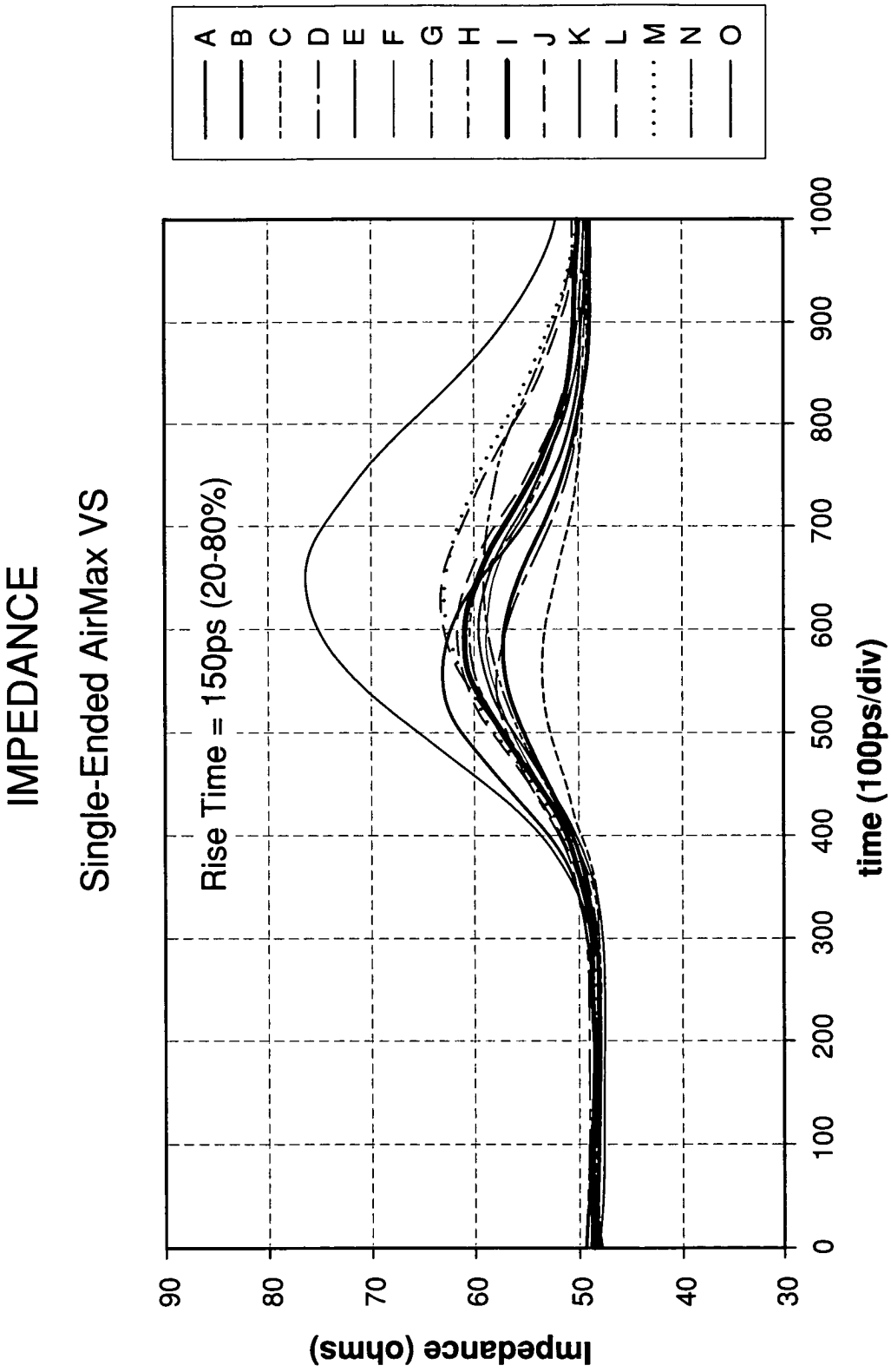

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
IMPEDANCE
Single-Ended AirMax VS
Rise Time = 150ps (20-80%)
impedance (ohms)
90
80
70
60
50
40
30
time (100ps/div)
0
100
200
300
400
500
600
700
800
900
1000

FIG. 44B

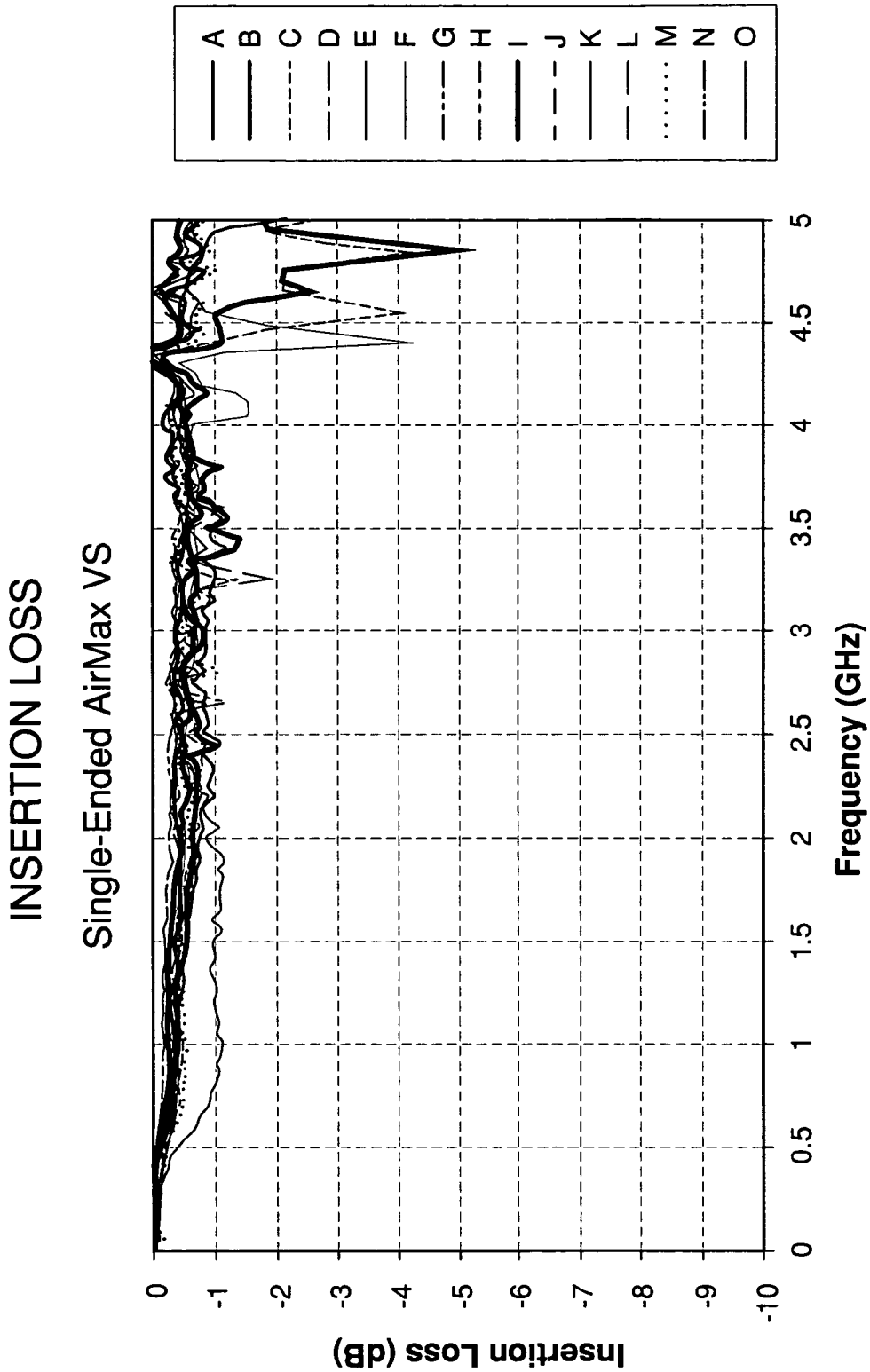

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
INSERTION LOSS
Single-Ended AirMax VS
Insertion Loss (dB)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Frequency (GHz)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

FIG. 44C

CROSSTALK

Worst-Case Multi-Active Near-End Crosstalk

150ps(20-80%)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	5.0	7.3	7.3	7.4	6.0	6.2	7.2	7.6	8.0	8.7	6.6	7.6	8.0	7.8	4.2

FIG. 44D

Worst-Case Multi-Active Far-End Crosstalk

150ps(20-80%)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	2.0	2.9	2.4	2.4	2.6	2.4	2.9	2.9	2.5	2.8	2.6	2.7	2.8	2.8	1.7

FIG. 44E

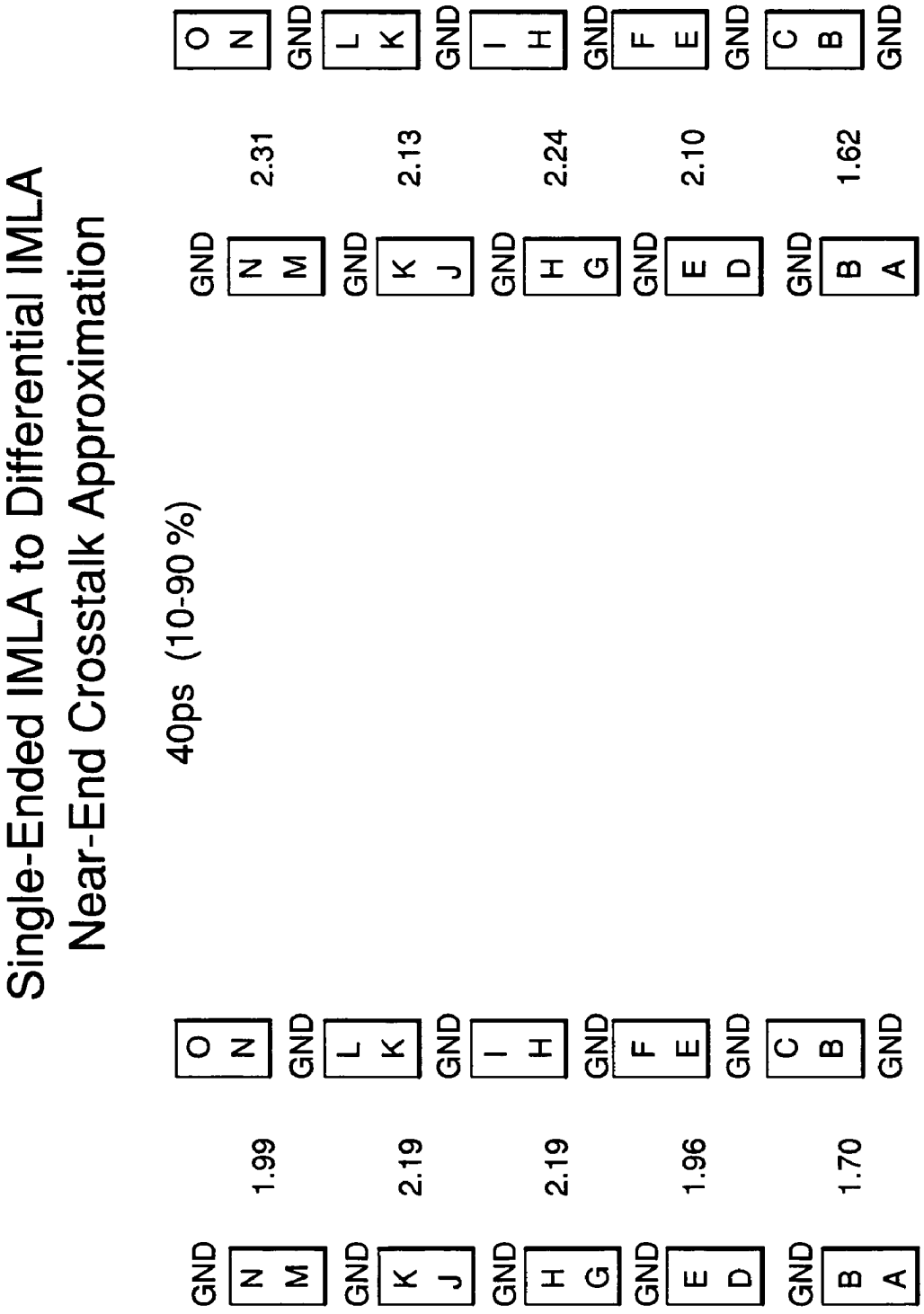

Single-Ended IMLA to Differential IMLA
Near-End Crosstalk Approximation
40ps (10-90 %)
GND N M GND K J GND H G GND E D GND B A
1.99 2.19 2.19 1.96 1.70
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A
2.31 2.13 2.24 2.10 1.62
O N GND L K GND I H GND F E GND C B GND

FIG. 45A

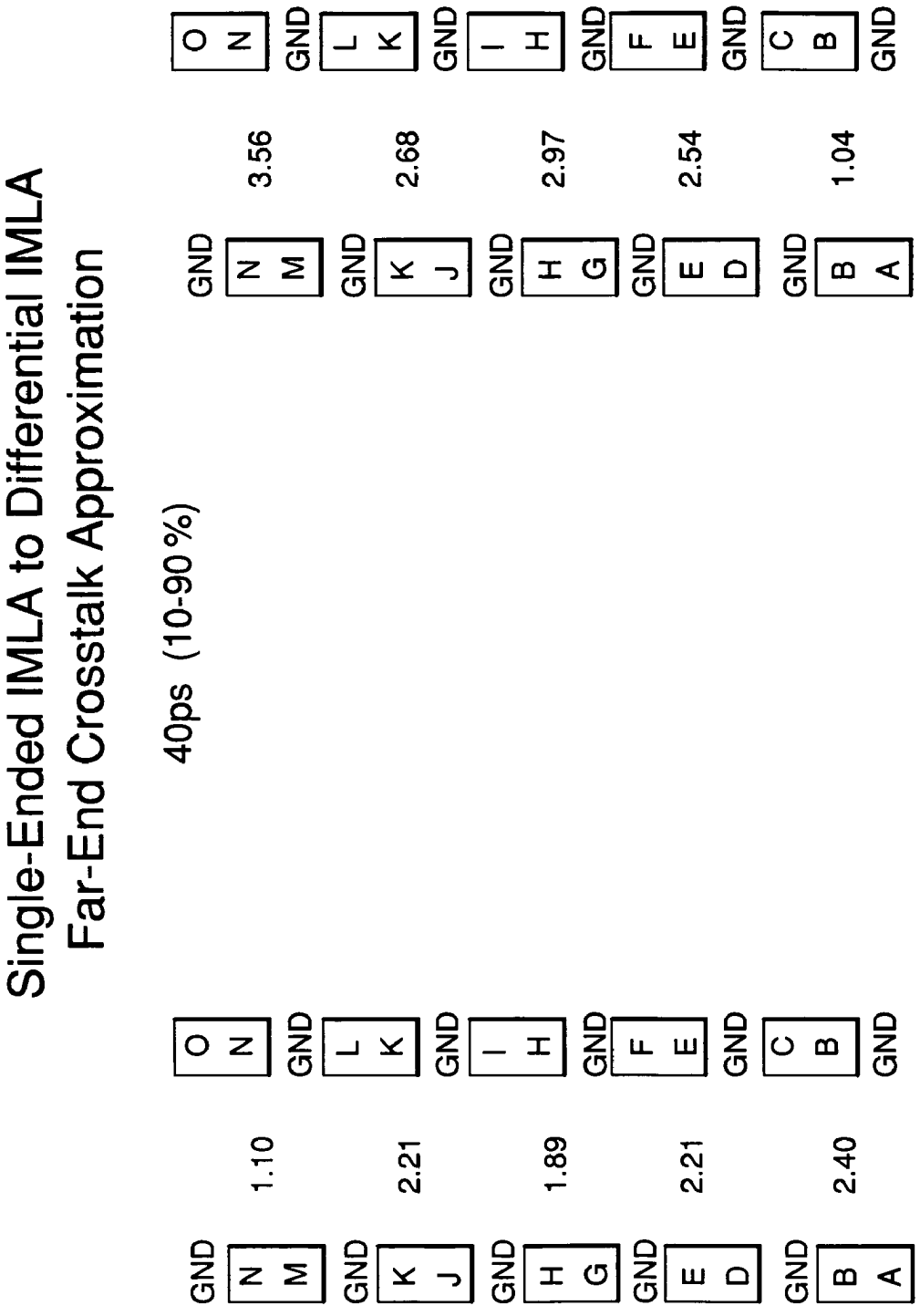

Single-Ended IMLA to Differential IMLA
Far-End Crosstalk Approximation
40ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
1.10 2.21 1.89 2.21 2.40
GND O N GND L K GND I H GND F E GND C B GND
GND O N GND L K GND I H GND F E GND C B GND
3.56 2.68 2.97 2.54 1.04
GND N M GND K J GND H G GND E D GND B A

FIG. 45B

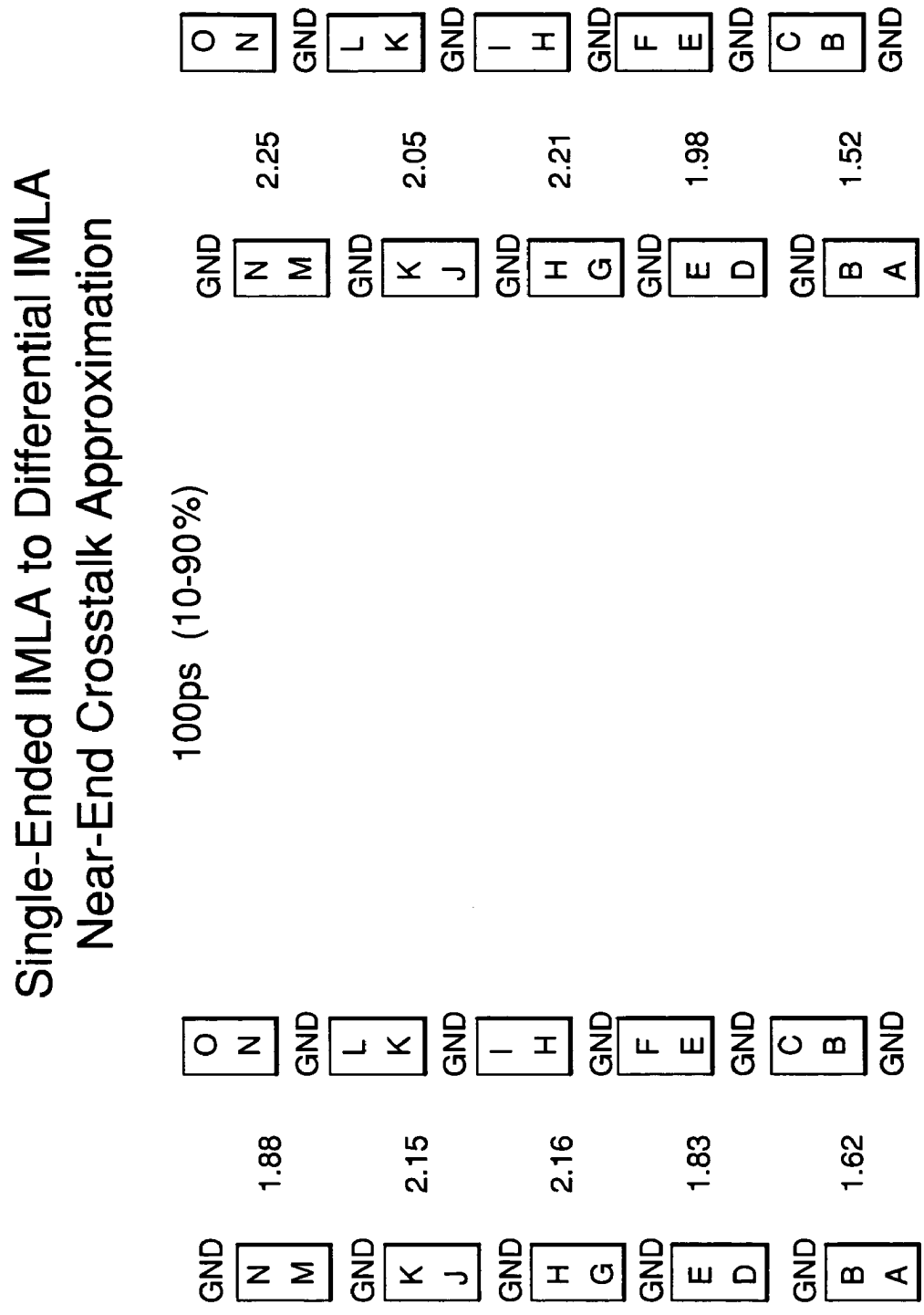

Single-Ended IMLA to Differential IMLA
Near-End Crosstalk Approximation
100ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
1.88 2.15 2.16 1.83 1.62
O N GND L K GND I H GND F E GND C B GND
2.25 2.05 2.21 1.98 1.52

FIG. 45C

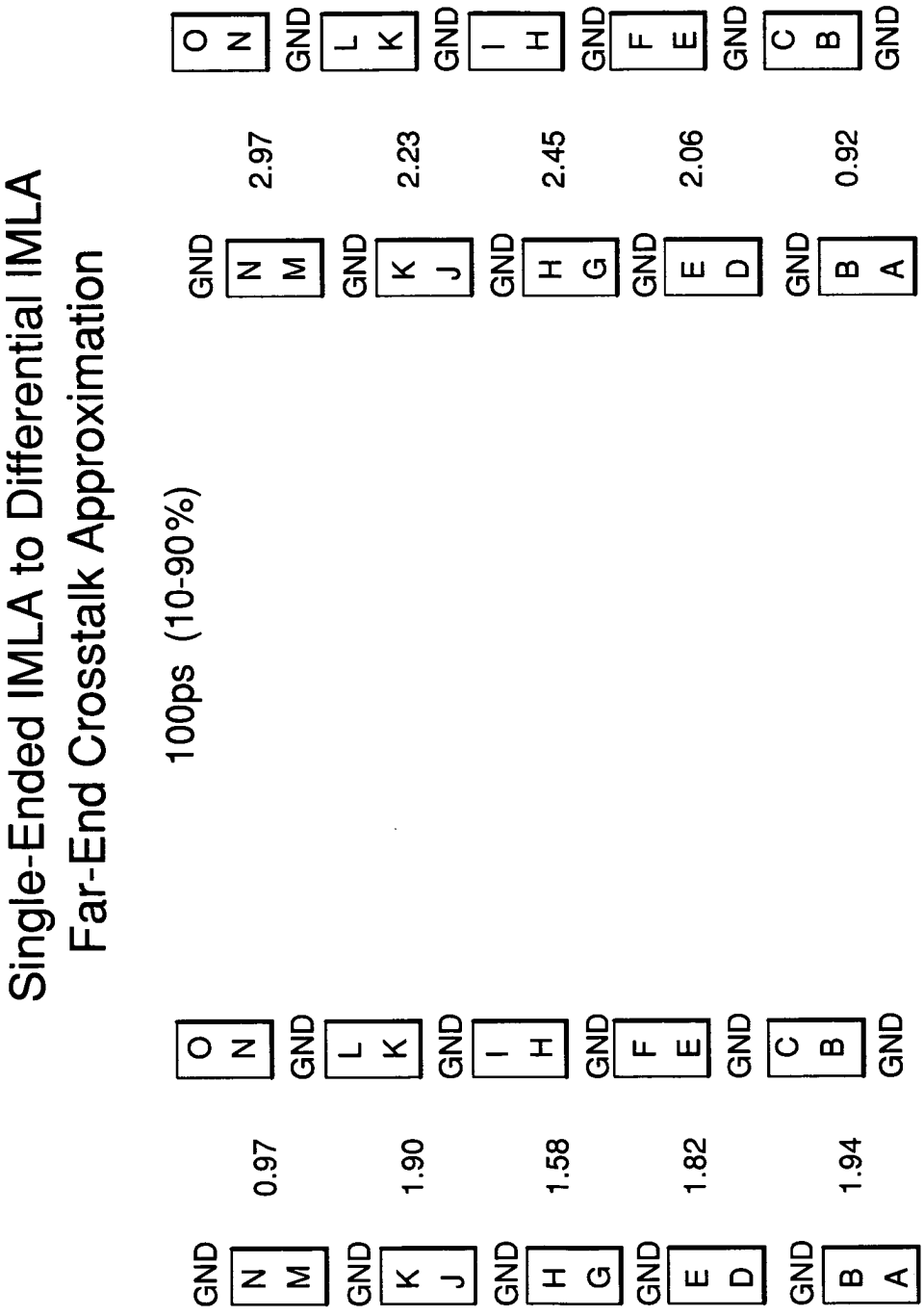

Single-Ended IMLA to Differential IMLA
Far-End Crosstalk Approximation
100ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
0.97 1.90 1.58 1.82 1.94
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A
2.97 2.23 2.45 2.06 0.92
O N GND L K GND I H GND F E GND C B GND

FIG. 45D

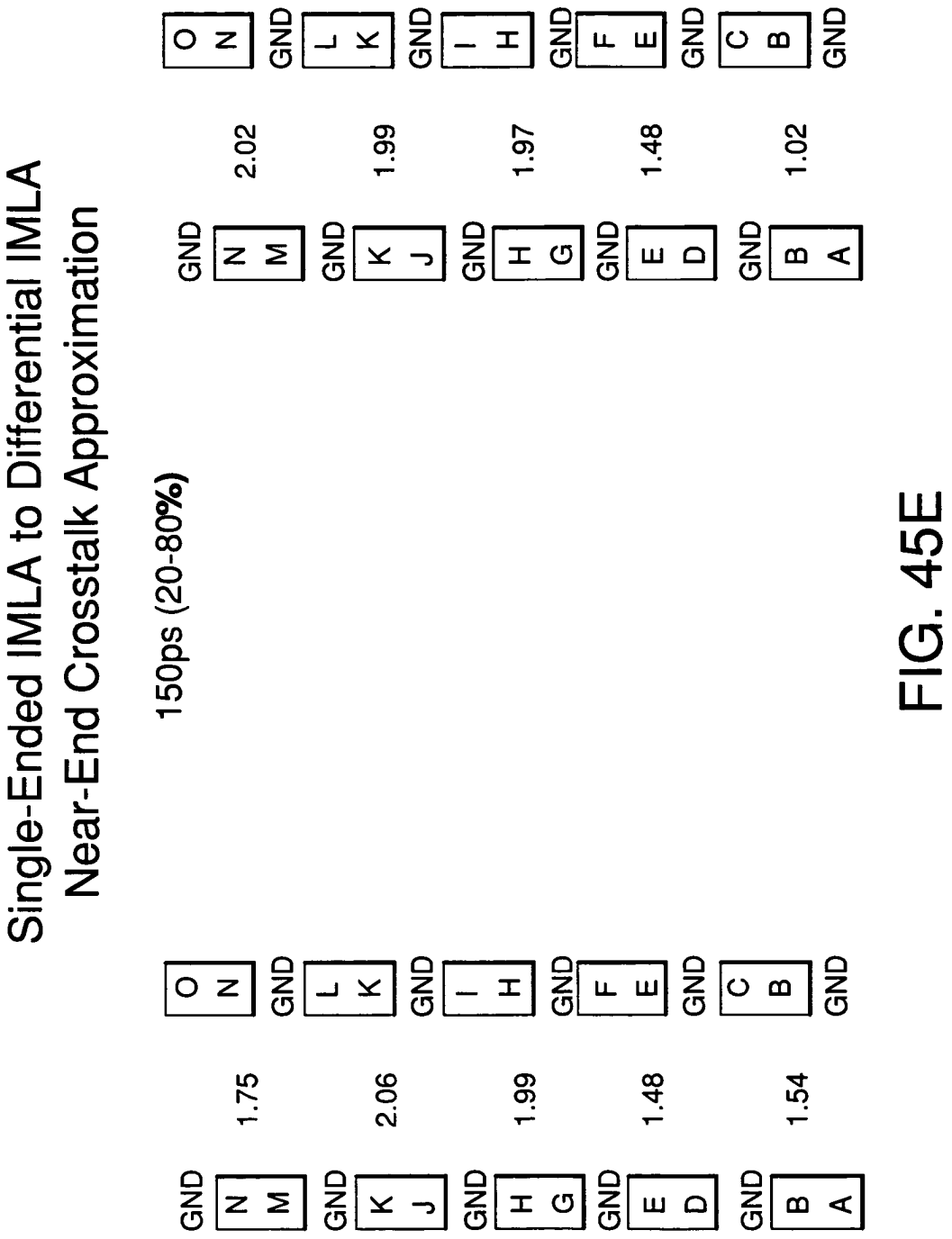

Single-Ended IMLA to Differential IMLA
Near-End Crosstalk Approximation
150ps (20-80%)
GND N M GND K J GND H G GND E D GND B A
1.75 2.06 1.99 1.48 1.54
GND O N GND L K GND I H GND F E GND C B GND
2.02 1.99 1.97 1.48 1.02
GND O N GND L K GND I H GND F E GND C B GND

FIG. 45E

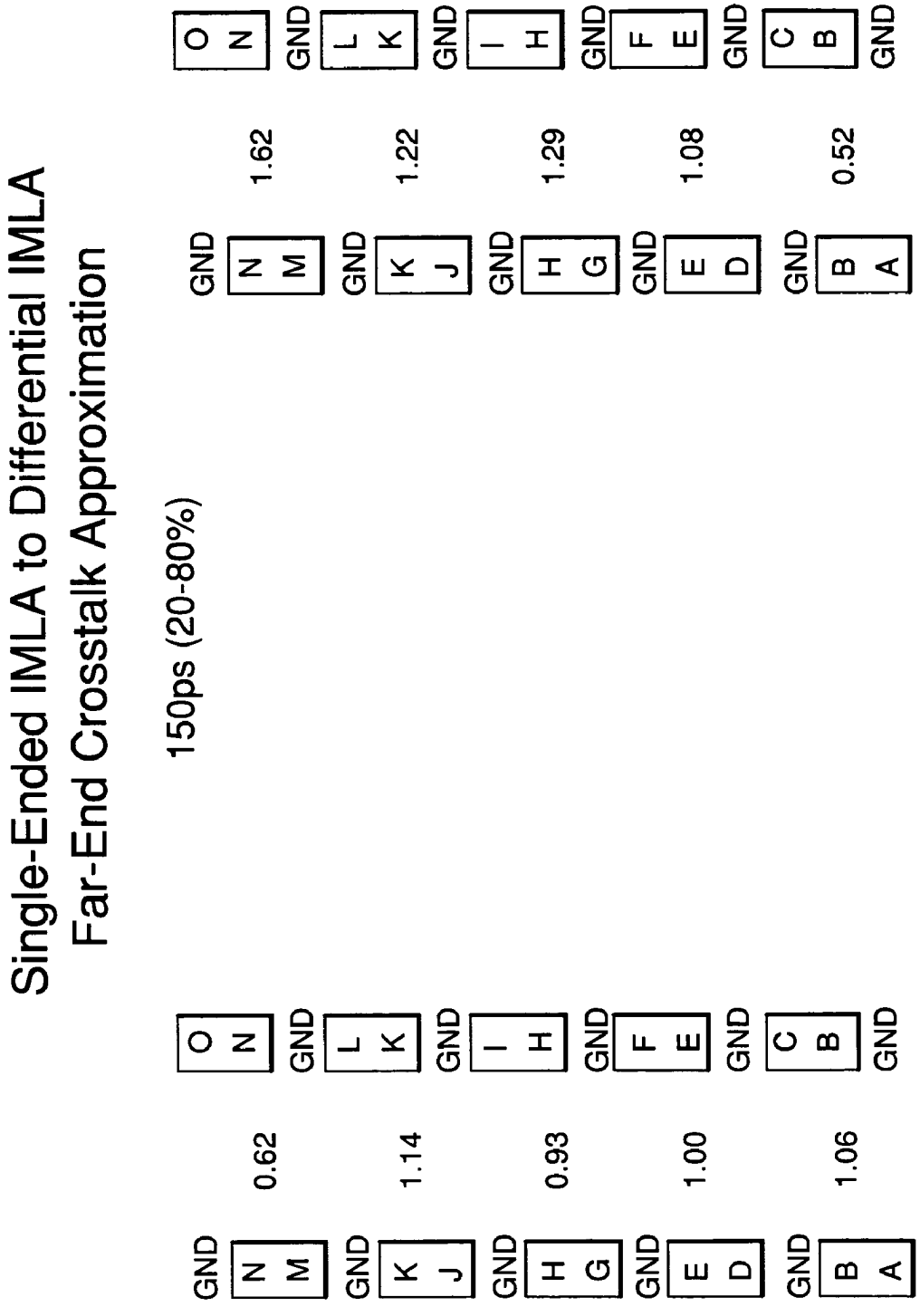

Single-Ended IMLA to Differential IMLA
Far-End Crosstalk Approximation
150ps (20-80%)
GND N M GND K J GND H G GND E D GND B A
0.62 1.14 0.93 1.00 1.06
O N GND L K GND I H GND F E GND C B GND
1.62 1.22 1.29 1.08 0.52
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A

FIG. 45F

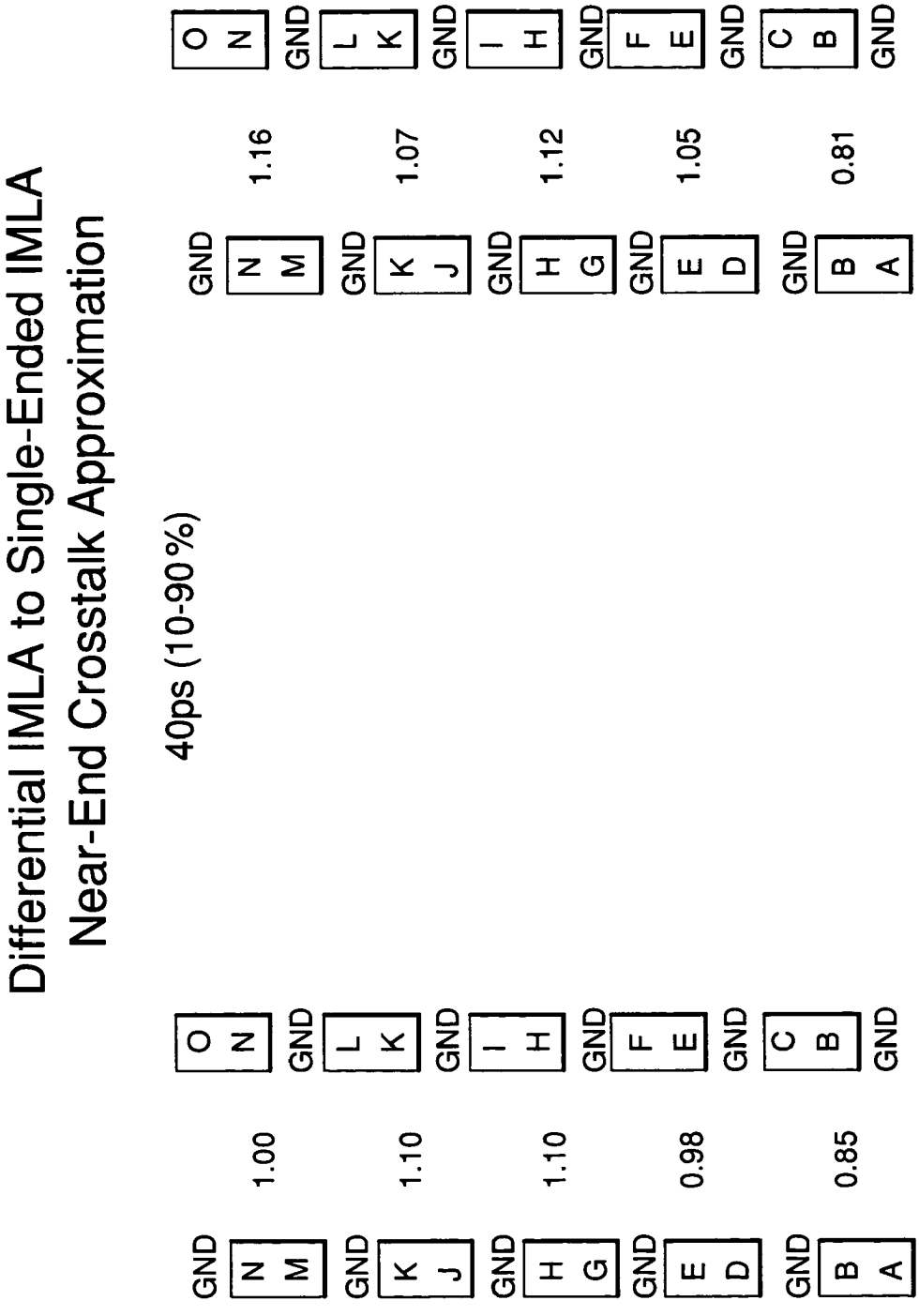

Differential IMLA to Single-Ended IMLA
Near-End Crosstalk Approximation
40ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
1.00 1.10 1.10 0.98 0.85
O N GND L K GND I H GND F E GND C B GND
1.16 1.07 1.12 1.05 0.81
O N GND L K GND I H GND F E GND C B GND

FIG. 46A

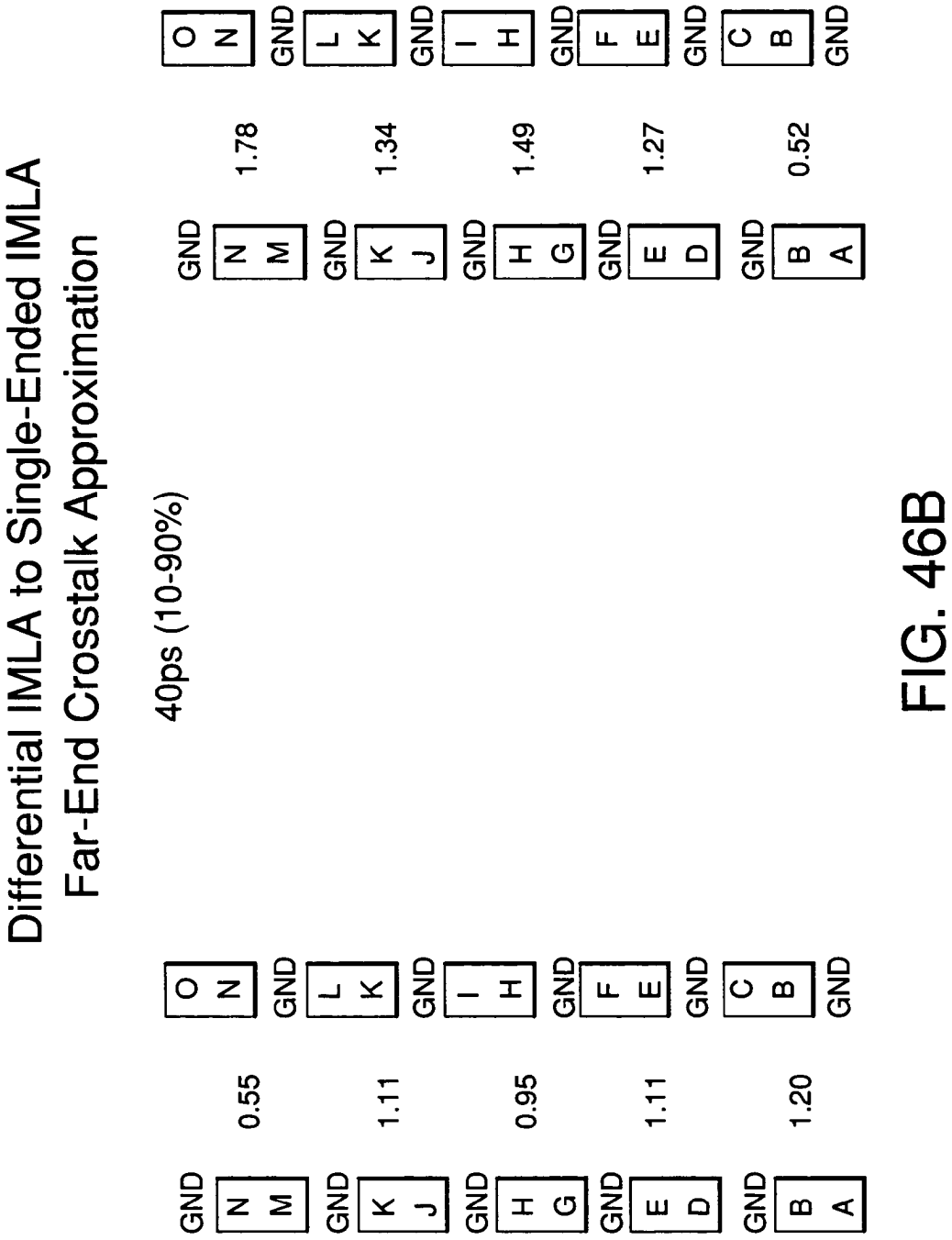

Differential IMLA to Single-Ended IMLA
Far-End Crosstalk Approximation
40ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
0.55 1.11 0.95 1.11 1.20
O N GND L K GND I H GND F E GND C B GND
1.78 1.34 1.49 1.27 0.52
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A

FIG. 46B

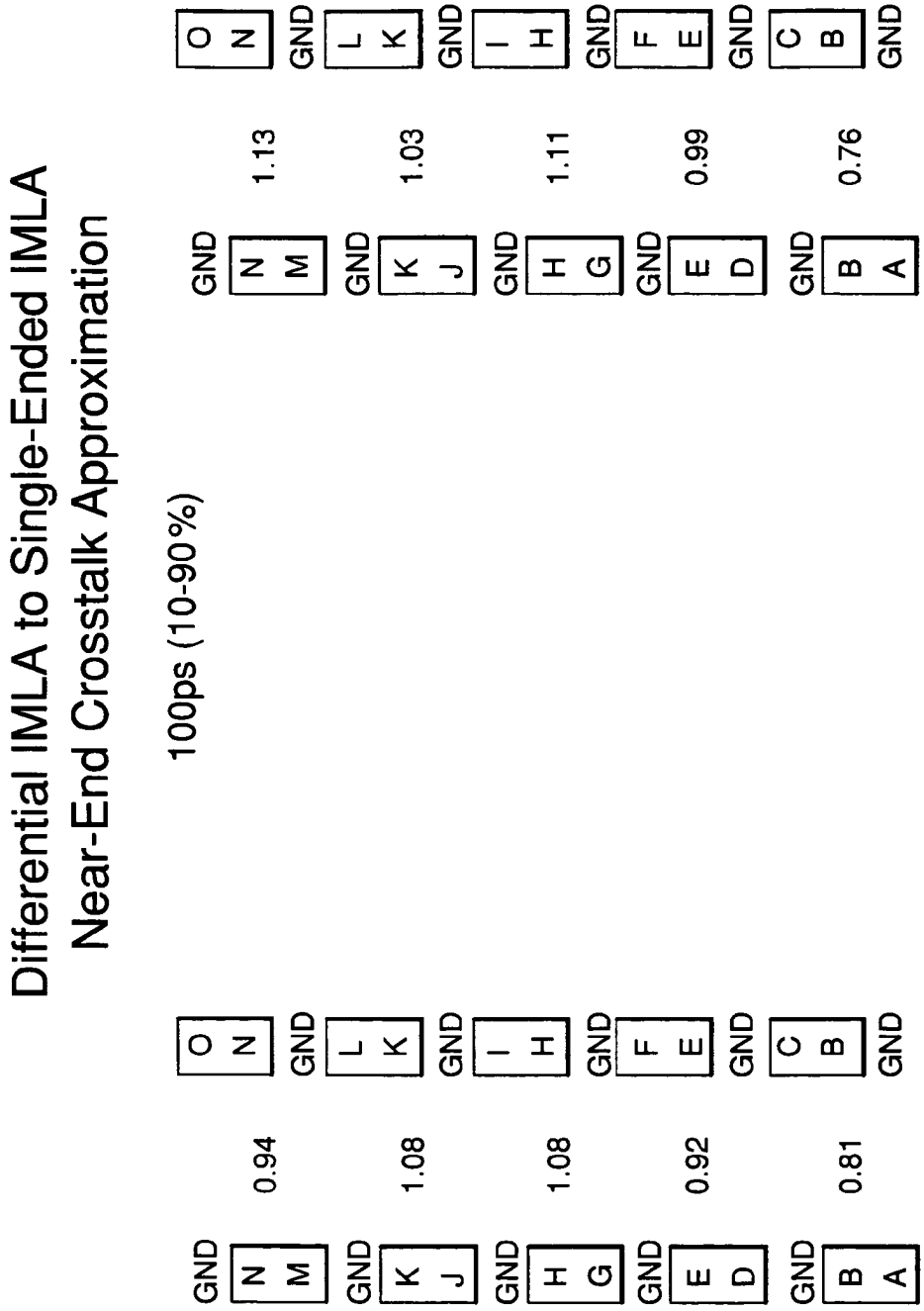

Differential IMLA to Single-Ended IMLA
Near-End Crosstalk Approximation
100ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
0.94
1.08
1.08
0.92
0.81
O N GND L K GND I H GND F E GND C B GND
1.13
1.03
1.11
0.99
0.76

FIG. 46C

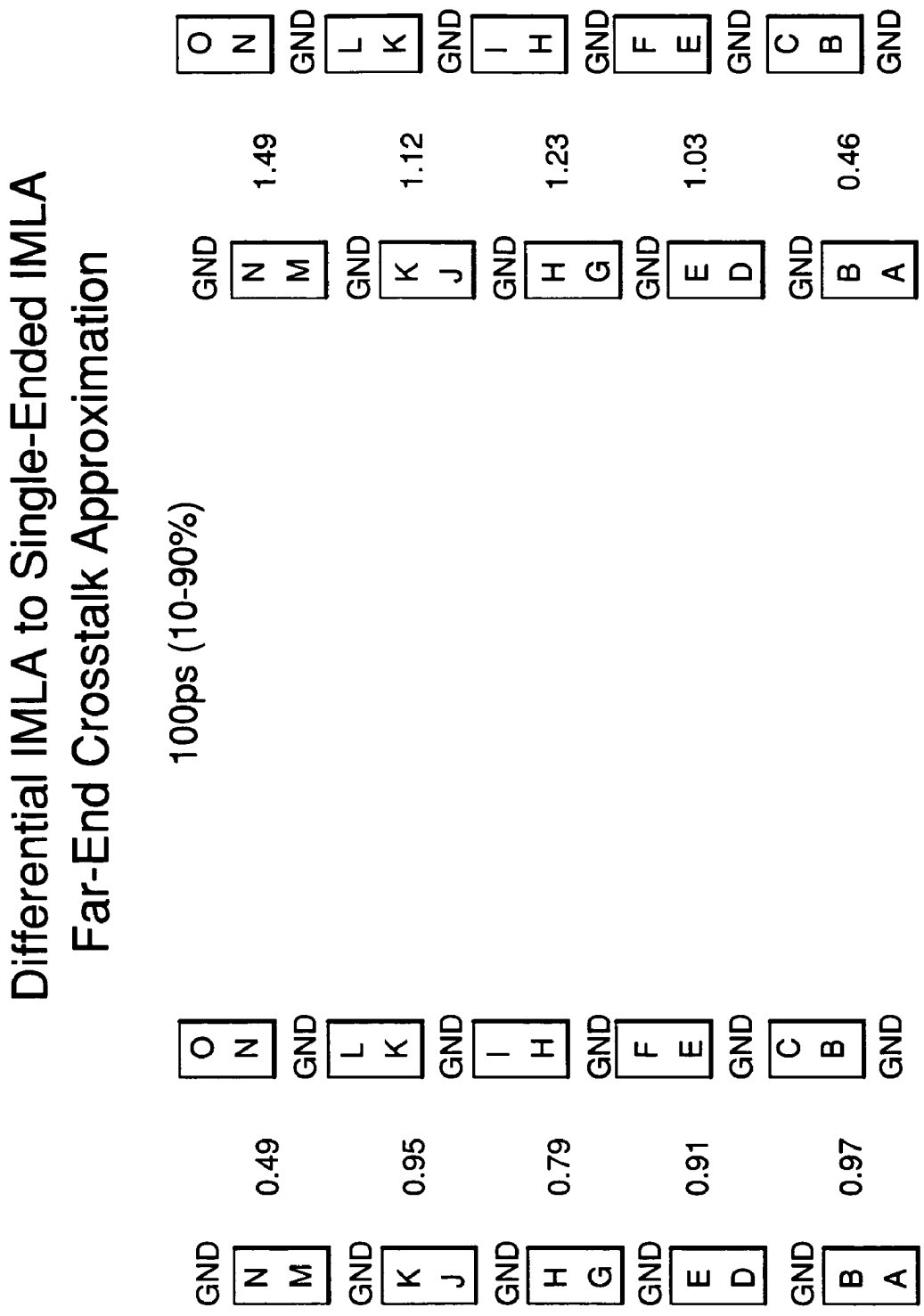

Differential IMLA to Single-Ended IMLA
Far-End Crosstalk Approximation
100ps (10-90%)
GND N M GND K J GND H G GND E D GND B A
0.49 0.95 0.79 0.91 0.97
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A
1.49 1.12 1.23 1.03 0.46
O N GND L K GND I H GND F E GND C B GND

FIG. 46D

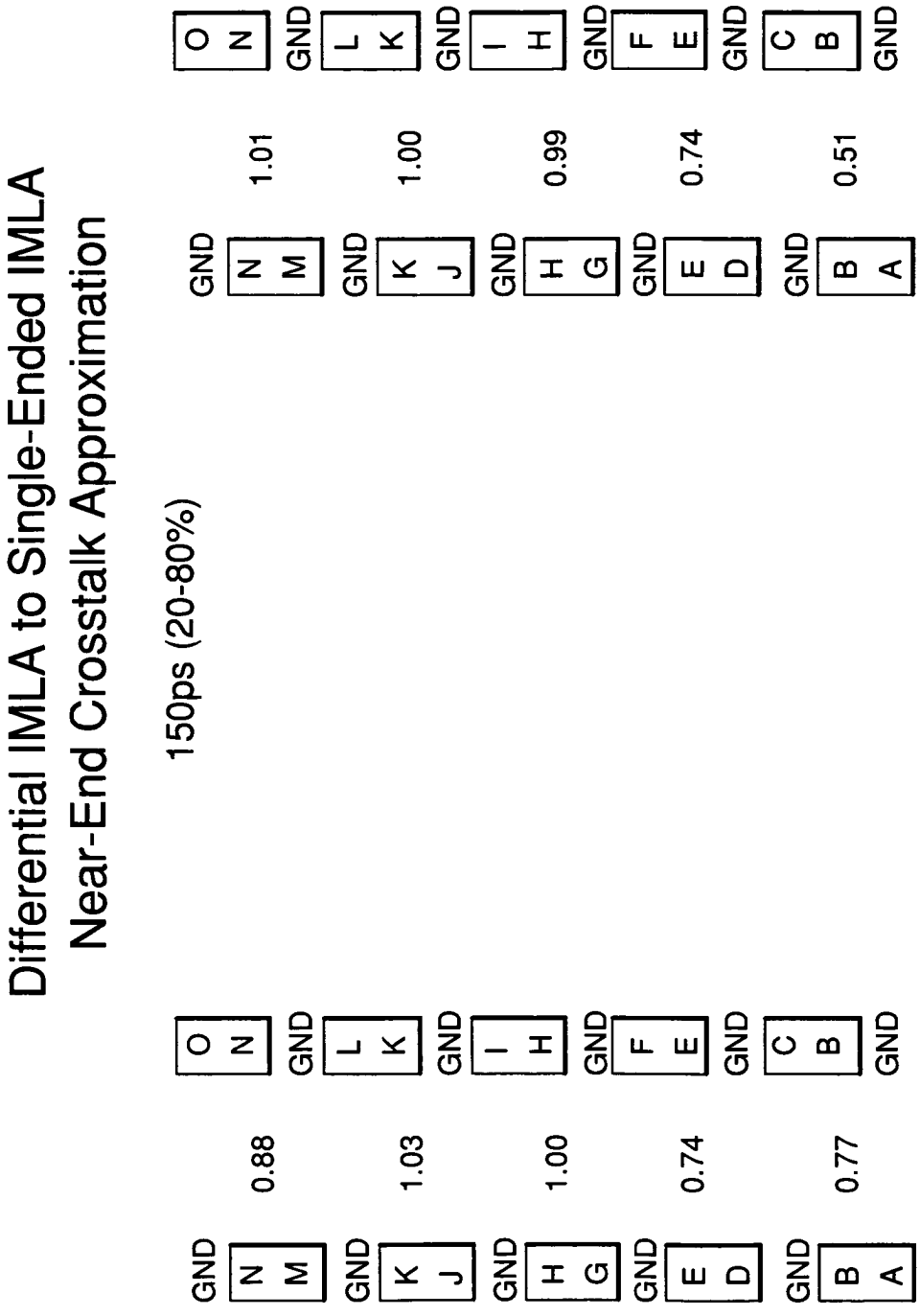

Differential IMLA to Single-Ended IMLA
Near-End Crosstalk Approximation
150ps (20-80%)
GND N M GND K J GND H G GND E D GND B A
0.88 1.03 1.00 0.74 0.77
GND O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A
1.01 1.00 0.99 0.74 0.51
GND O N GND L K GND I H GND F E GND C B GND

FIG. 46E

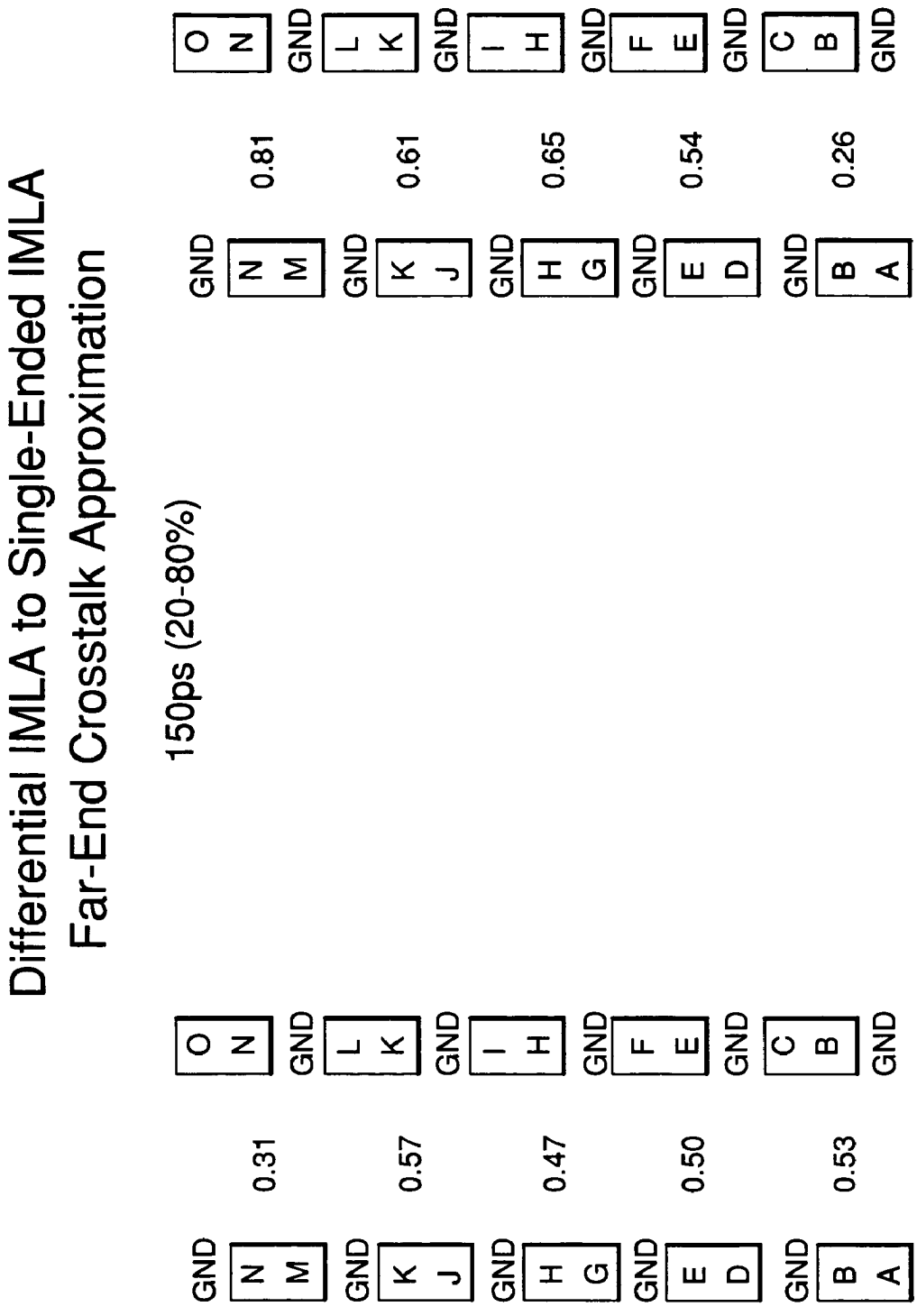

Differential IMLA to Single-Ended IMLA
Far-End Crosstalk Approximation
150ps (20-80%)
GND N M GND K J GND H G GND E D GND B A
0.31 0.57 0.47 0.50 0.53
O N GND L K GND I H GND F E GND C B GND
GND N M GND K J GND H G GND E D GND B A
0.81 0.61 0.65 0.54 0.26
O N GND L K GND I H GND F E GND C B GND

FIG. 46F

SHIELDLESS, HIGH-SPEED ELECTRICAL CONNECTORS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 10/634,547, filed Aug. 5, 2003 now U.S. Pat. No. 6,994,569, which is a continuation-in-part of U.S. patent application Ser. No. 10/294,966, filed Nov. 14, 2002, now U.S. Pat. No. 6,976,886, which is a continuation-in-part of U.S. patent application Ser. No. 09/990,794, filed Nov. 14, 2001, now U.S. Pat. No. 6,692,272, and of U.S. patent application Ser. No. 10/155,786, filed May 24, 2002, now U.S. Pat. No. 6,652,318. The contents of each of the above-referenced U.S. patents and patent applications are incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

Generally, the invention relates to the field of electrical connectors. More particularly, the invention relates to an electrical connector having a linear array of electrical blade contacts, wherein the contacts are elongated in a direction along the linear array.

BACKGROUND OF THE INVENTION

Electrical connectors provide signal connections between electronic devices using signal contacts. Often, the signal contacts are so closely spaced that undesirable interference, or "cross talk," occurs between adjacent signal contacts. As used herein, the term "adjacent" refers to contacts (or rows or columns) that are next to one another. Cross talk occurs when one signal contact induces electrical interference in an adjacent signal contact due to intermingling electrical fields, thereby compromising signal integrity. With electronic device miniaturization and high speed, high signal integrity electronic communications becoming more prevalent, the reduction of cross talk becomes a significant factor in connector design.

One commonly used technique for reducing cross talk is to position separate electrical shields, in the form of metallic plates, for example, between adjacent signal contacts. The shields act to block cross talk between the signal contacts by blocking the intermingling of the contacts' electric fields. FIGS. **1**A and **1**B depict exemplary contact arrangements for electrical connectors that use shields to block cross talk.

FIG. **1**A depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along columns **101**–**106**. As shown, shields **112** can be positioned between contact columns **101**–**106**. A column **101**–**106** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same column. The shields **112** serve to block cross talk between differential signal pairs in adjacent columns.

FIG. **1**B depicts an arrangement in which signal contacts S and ground contacts G are arranged such that differential signal pairs S+, S− are positioned along rows **111**–**116**. As shown, shields **122** can be positioned between rows **111**–**116**. A row **111**–**116** can include any combination of signal contacts S+, S− and ground contacts G. The ground contacts G serve to block cross talk between differential signal pairs in the same row. The shields **122** serve to block cross talk between differential signal pairs in adjacent rows.

Because of the demand for smaller, lower weight communications equipment, it is desirable that connectors be made smaller and lower in weight, while providing the same performance characteristics. Shields take up valuable space within the connector that could otherwise be used to provide additional signal contacts, and thus limit contact density (and, therefore, connector size). Additionally, manufacturing and inserting such shields substantially increase the overall costs associated with manufacturing such connectors. In some applications, shields are known to make up 40% or more of the cost of the connector. Another known disadvantage of shields is that they lower impedance. Thus, to make the impedance high enough in a high contact density connector, the contacts would need to be so small that they would not be robust enough for many applications.

The dielectrics that are typically used to insulate the contacts and retain them in position within the connector also add undesirable cost and weight.

Therefore, a need exists for a lightweight, high-speed electrical connector (i.e., one that operates above 1 Gb/s and typically in the range of about 10 Gb/s) that reduces the occurrence of cross talk without the need for separate shields, and provides for a variety of other benefits not found in prior art connectors.

SUMMARY OF THE INVENTION

An electrical connector according to the invention may include a linear array of electrical blade contacts, each having a free-ended mating portion that extends from a mate surface of a dielectric base. The linear array may include a first signal contact, a second signal contact positioned adjacent to the first signal contact and forming a differential signal pair therewith, and a ground contact positioned adjacent to the second signal contact. The first signal contact, the second signal contact, and the ground contact may each be elongated in a direction along the linear array. The ground contact may extend farther from the dielectric base than does either of the signal contacts.

Each of the signal contacts may have a cross-section defining an edge and a broadside. The signal contacts may be positioned edge-to-edge, and may be edge-coupled to one another. The broadside of at least one of the signal contacts may twice as long as the edge thereof. The signal contacts define a gap between the edges thereof. A dielectric material may be disposed between the edges of the signal contacts. The gap may have a gap width that is a function of the dielectric material. The dielectric may be air, and the gap width may be approximately 0.3 to 0.4 mm.

The electrical connector may include a second linear array of electrical contacts that is adjacent to the first linear array of electrical contacts. The second linear array may include a second differential signal pair, which may be offset with respect to the first differential signal pair in a direction along which the second linear array of electrical contacts extends. The second linear array may be staggered relative to the first linear array. A differential signal in the first differential signal pair may produce an electric field having a first electric field strength in a gap between the first and second electrical contacts and a second electric field strength near the second differential signal pair. The second electric field strength may be lower than the first electric field strength.

The dielectric base may define a hole transverse to the first direction at a center portion of the dielectric base. Intermediate portions of each of the blade contacts may be exposed to air. The dielectric base may define respective contact through-holes for each of the blade contacts.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B depict exemplary contact arrangements for electrical connectors that use shields to block cross talk.

FIG. **2**A is a schematic illustration of an electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry.

FIG. **2**B depicts equipotential regions within an arrangement of signal and ground contacts.

FIG. **3**A illustrates a conductor arrangement used to measure the effect of offset on multi-active cross talk.

FIG. **3**B is a graph illustrating the relationship between multi-active cross talk and offset between adjacent columns of terminals in accordance with one aspect of the invention.

FIG. **3**C depicts a contact arrangement for which cross talk was determined in a worst case scenario.

FIGS. **4**A–**4**C depict conductor arrangements in which signal pairs are arranged in columns.

FIG. **5** depicts a conductor arrangement in which signal pairs are arranged in rows.

FIG. **6** is a diagram showing an array of six columns of terminals arranged in accordance with one aspect of the invention.

FIG. **7** is a diagram showing an array of six columns arranged in accordance with another embodiment of the invention.

FIG. **8** is a perspective view of an illustrative right angle electrical connector, in accordance with the invention.

FIG. **9** is a side view of the right angle electrical connector of FIG. **8**.

FIG. **10** is an end view of a portion of the right angle electrical connector of FIG. **8**.

FIG. **11** is a top view of a portion of the right angle electrical connector of FIG. **8**.

FIG. **12** is a top cut-away view of conductors of the right angle electrical connector of FIG. **9** taken along line B—B.

FIG. **13**A is a side cut-away view of a portion of the right angle electrical connector of FIG. **9** taken along line A—A.

FIG. **13**B is a cross-sectional view taken along line C—C of FIG. **13**A.

FIG. **14** is a perspective view of illustrative conductors of a right angle electrical connector according to the invention.

FIG. **15** is a perspective view of another illustrative conductor of the right angle electrical connector of FIG. **8**.

FIG. **16**A is a perspective view of a backplane system having an exemplary right angle electrical connector.

FIG. **16**B is a simplified view of an alternative embodiment of a backplane system with a right angle electrical connector.

FIG. **16**C is a simplified view of a board-to-board system having a vertical connector.

FIG. **17** is a perspective view of the connector plug portion of the connector shown in FIG. **16**A.

FIG. **18** is a side view of the plug connector of FIG. **17**.

FIG. **19**A is a side view of a lead assembly of the plug connector of FIG. **17**.

FIG. **19**B depicts the lead assembly of FIG. **19** during mating.

FIG. **20** is an end view of two columns of terminals in accordance with one embodiment of the invention.

FIG. **21** is a side view of the terminals of FIG. **20**.

FIG. **22** is a perspective top view of a receptacle in accordance with another embodiment of the invention.

FIG. **23** is a side view of the receptacle of FIG. **22**.

FIG. **24** is a perspective view of a single column of receptacle contacts.

FIG. **25** is a perspective view of a connector in accordance with another embodiment of the invention.

FIG. **26** is a side view of a column of right angle terminals in accordance with another aspect of the invention.

FIGS. **27** and **28** are front views of the right angle terminals of FIG. **26** taken along lines A—A and lines B—B respectively.

FIG. **29** illustrates the cross section of terminals as the terminals connect to vias on an electrical device in accordance with another aspect of the invention.

FIG. **30** is a perspective view of a portion of another illustrative right angle electrical connector, in accordance with the invention.

FIG. **31** is a perspective view of another illustrative right angle electrical connector, in accordance with the invention.

FIG. **32** is a perspective view of an alternative embodiment of a receptacle connector.

FIG. **33** is a flow diagram of a method for making a connector in accordance with the invention.

FIGS. **34**A and **34**B are perspective views of example embodiments of a header assembly for a connector according to the invention.

FIGS. **35**A and **35**B are perspective views of example embodiments of a receptacle assembly for a connector according to the invention.

FIG. **36** is a side view of an example embodiment of a connector according to the invention connecting signal paths between two circuit boards.

FIG. **37** is a side view of an example embodiment of an insert molded lead assembly according to the invention.

FIGS. **38**A–**38**C depict example contact designations for an IMLA such as depicted in FIG. **37**.

FIG. **39** is a side view of another example embodiment of an insert molded lead assembly according to the invention.

FIGS. **40**A–**40**C depict example contact designations for an IMLA such as depicted in FIG. **39**.

FIG. **41** depicts example differential signal pair contact designations for adjacent contact arrays.

FIGS. **42**A–D provide graphs of measured performance for adjacent contact arrays such as depicted in FIG. **41**.

FIG. **43** depicts example single-ended signal contact designations for adjacent contact arrays.

FIGS. **44**A–E provide graphs of measured performance for adjacent contact arrays such as depicted in FIG. **43**.

FIGS. **45**A–**45**F provide cross-talk measurements for a single-ended aggressor injecting noise onto a differential pair.

FIGS. **46**A–**46**F provide cross-talk measurements for a differential pair aggressor injecting noise onto a single-ended contact.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Certain terminology may be used in the following description for convenience only and should not be considered as limiting the invention in any way. For example, the terms "top," "bottom," "left," "right," "upper," and "lower" designate directions in the figures to which reference is made. Likewise, the terms "inwardly" and "outwardly" designate directions toward and away from, respectively, the geometric center of the referenced object. The terminology includes the words above specifically mentioned, derivatives thereof, and words of similar import.

I-Shaped Geometry for Electrical Connectors—Theoretical Model

FIG. **2**A is a schematic illustration of an electrical connector in which conductive and dielectric elements are arranged in a generally "I" shaped geometry. Such connectors are embodied in the assignee's "I-BEAM" technology, and are described and claimed in U.S. Pat. No. 5,741,144, entitled "Low Cross And Impedance Controlled Electric Connector," the disclosure of which is herein incorporated by reference in its entirety. Low cross talk and controlled impedance have been found to result from the use of this geometry.

As shown in FIG. **2**A, the conductive element can be perpendicularly interposed between two parallel dielectric and ground plane elements. The description of this transmission line geometry as I-shaped comes from the vertical arrangement of the signal conductor shown generally at numeral **10** between the two horizontal dielectric layers **12** and **14** having a dielectric constant ϵ and ground planes **13** and **15** symmetrically placed at the top and bottom edges of the conductor. The sides **20** and **22** of the conductor are open to the air **24** having an air dielectric constant c. In a connector application, the conductor could include two sections, **26** and **28**, that abut end-to-end or face-to-face. The thickness, t_1 and t_2 of the dielectric layers **12** and **14**, to first order, controls the characteristic impedance of the transmission line and the ratio of the overall height h to dielectric width w_d controls the electric and magnetic field penetration to an adjacent contact. Original experimentation led to the conclusion that the ratio h/w_d needed to minimize interference beyond A and B would be approximately unity (as illustrated in FIG. **2**A).

The lines **30**, **32**, **34**, **36** and **38** in FIG. **2**A are equipotentials of voltage in the air-dielectric space. Taking an equipotential line close to one of the ground planes and following it out towards the boundaries A and B, it will be seen that both boundary A or boundary B are very close to the ground potential. This means that virtual ground surfaces exist at each of boundary A and boundary B. Therefore, if two or more I-shaped modules are placed side-by-side, a virtual ground surface exists between the modules and there will be little to no intermingling of the modules' fields. In general, the conductor width w_c and dielectric thicknesses t_1, t_2 should be small compared to the dielectric width w_d or module pitch (i.e., distance between adjacent modules).

Given the mechanical constraints on a practical connector design, it was found in actuality that the proportioning of the signal conductor (blade/beam contact) width and dielectric thicknesses could deviate somewhat from the preferred ratios and some minimal interference might exist between adjacent signal conductors. However, designs using the above-described I-shaped geometry tend to have lower cross talk than other conventional designs.

Exemplary Factors Affecting Cross Talk Between Adjacent Contacts

In accordance with the invention, the basic principles described above were further analyzed and expanded upon and can be employed to determine how to even further limit cross talk between adjacent signal contacts, even in the absence of shields between the contacts, by determining an appropriate arrangement and geometry of the signal and ground contacts. FIG. **2**B includes a contour plot of voltage in the neighborhood of an active column-based differential signal pair S+, S− in a contact arrangement of signal contacts S and ground contacts G according to the invention. As shown, contour lines **42** are closest to zero volts, contour lines **44** are closest to −1 volt, and contour lines **46** are closest to +1 volt. It has been observed that, although the voltage does not necessarily go to zero at the "quiet" differential signal pairs that are nearest to the active pair, the interference with the quiet pairs is near zero. That is, the voltage impinging on the positive-going quiet differential pair signal contact is about the same as the voltage impinging on the negative-going quiet differential pair signal contact. Consequently, the noise on the quiet pair, which is the difference in voltage between the positive- and negative-going signals, is close to zero.

Thus, as shown in FIG. **2**B, the signal contacts S and ground contacts G can be scaled and positioned relative to one another such that a differential signal in a first differential signal pair produces a high field H in the gap between the contacts that form the signal pair and a low (i.e., close to ground potential) field L (close to ground potential) near an adjacent signal pair. Consequently, cross talk between adjacent signal contacts can be limited to acceptable levels for the particular application. In such connectors, the level of cross talk between adjacent signal contacts can be limited to the point that the need for (and cost of) shields between adjacent contacts is unnecessary, even in high speed, high signal integrity applications.

Through further analysis of the above-described I-shaped model, it has been found that the unity ratio of height to width is not as critical as it first seemed. It has also been found that a number of factors can affect the level of cross talk between adjacent signal contacts. A number of such factors are described in detail below, though it is anticipated that there may be others. Additionally, though it is preferred that all of these factors be considered, it should be understood that each factor may, alone, sufficiently limit cross talk for a particular application. Any or all of the following factors may be considered in determining a suitable contact arrangement for a particular connector design:

a) Less cross talk has been found to occur where adjacent contacts are edge-coupled (i.e., where the edge of one contact is adjacent to the edge of an adjacent contact) than where adjacent contacts are broad side coupled (i.e., where the broad side of one contact is adjacent to the broad side of an adjacent contact) or where the edge of one contact is adjacent to the broad side of an adjacent contact. The tighter the edge coupling, the less the coupled signal pair's electrical field will extend towards an adjacent pair and the less towards the unity height-to-width ratio of the original I-shaped theoretical model a connector application will have to approach. Edge coupling also allows for smaller gap widths between adjacent connectors, and thus facilitates the achievement of desirable impedance levels in high contact density connectors without the need for contacts that are too small to perform adequately. For example, it has been found that a gap of about 0.3–0.4 mm is adequate to provide an impedance of about 100 ohms where the contacts are edge coupled, while a gap of about 1 mm is necessary where the same contacts are broad side coupled to achieve the same impedance. Edge coupling also facilitates changing contact width, and therefore gap width, as the contact extends through dielectric regions, contact regions, etc.;

b) It has also been found that cross talk can be effectively reduced by varying the "aspect ratio," i.e., the ratio of column pitch (i.e., the distance between adjacent columns) to the gap between adjacent contacts in a given column;

c) The "staggering" of adjacent columns relative to one another can also reduce the level of cross talk. That is, cross talk can be effectively limited where the signal contacts in a first column are offset relative to adjacent signal contacts in

an adjacent column. The amount of offset may be, for example, a full row pitch (i.e., distance between adjacent rows), half a row pitch, or any other distance that results in acceptably low levels of cross talk for a particular connector design. It has been found that the optimal offset depends on a number of factors, such as column pitch, row pitch, the shape of the terminals, and the dielectric constant(s) of the insulating material(s) around the terminals, for example. It has also been found that the optimal offset is not necessarily "on pitch," as was often thought. That is, the optimal offset may be anywhere along a continuum, and is not limited to whole fractions of a row pitch (e.g., full or half row pitches).

FIG. **3**A illustrates a contact arrangement that has been used to measure the effect of offset between adjacent columns on cross talk. Fast (e.g., 40 ps) rise-time differential signals were applied to each of Active Pair **1** and Active Pair **2**. Near-end crosstalk Nxt**1** and Nxt**2** were determined at Quiet Pair, to which no signal was applied, as the offset d between adjacent columns was varied from 0 to 5.0 mm. Near-end cross talk occurs when noise is induced on the quiet pair from the current carrying contacts in an active pair.

As shown in the graph of FIG. **3**B, the incidence of multi-active cross talk (thicker solid line in FIG. **3**B) is minimized at offsets of about 1.3 mm and about 3.65 mm. In this experiment, multi-active cross talk was considered to be the sum of the absolute values of cross talk from each of Active Pair **1** (dashed line in FIG. **3**B) and Active Pair **2** (thin solid line in FIG. **3**B). Thus, it has been shown that adjacent columns can be variably offset relative to one another until an optimum level of cross talk between adjacent pairs (about 1.3 mm, in this example);

d) Through the addition of outer grounds, i.e., the placement of ground contacts at alternating ends of adjacent contact columns, both near-end cross talk ("NEXT") and far-end cross talk ("FEXT") can be further reduced;

e) It has also been found that scaling the contacts (i.e., reducing the absolute dimensions of the contacts while preserving their proportional and geometric relationship) provides for increased contact density (i.e., the number of contacts per linear inch) without adversely affecting the electrical characteristics of the connector.

By considering any or all of these factors, a connector can be designed that delivers high-performance (i.e., low incidence of cross talk), high-speed (e.g., greater than 1 Gb/s and typically about 10 Gb/s) communications even in the absence of shields between adjacent contacts. It should also be understood that such connectors and techniques, which are capable of providing such high speed communications, are also useful at lower speeds. Connectors according to the invention have been shown, in worst case testing scenarios, to have near-end cross talk of less than about 3% and far-end cross talk of less than about 4%, at 40 picosecond rise time, with 63.5 mated signal pairs per linear inch. Such connectors can have insertion losses of less than about 0.7 dB at 5 GHz, and impedance match of about 100±8 ohms measured at a 40 picosecond rise time.

FIG. **3**C depicts a contact arrangement for which cross talk was determined in a worst case scenario. Cross talk from each of six attacking pairs S**1**, S**2**, S**3**, S**4**, S**5**, and S**6** was determined at a "victim" pair V. Attacking pairs S**1**, S**2**, S**3**, S**4**, S**5**, and S**6** are six of the eight nearest neighboring pairs to signal pair V. It has been determined that the additional affects on cross talk at victim pair V from attacking pairs S**7** and S**8** is negligible. The combined cross talk from the six nearest neighbor attacking pairs has been determined by summing the absolute values of the peak cross talk from each of the pairs, which assumes that each pair is fairing at the highest level all at the same time. Thus, it should be understood that this is a worst case scenario, and that, in practice, much better results should be achieved.

Exemplary Contact Arrangements According to the Invention

FIG. **4**A depicts a connector **100** according to the invention having column-based differential signal pairs (i.e., in which differential signal pairs are arranged into columns). (As used herein, a "column" refers to the direction along which the contacts are edge coupled. A "row" is perpendicular to a column.) As shown, each column **401**–**406** comprises, in order from top to bottom, a first differential signal pair, a first ground conductor, a second differential signal pair, and a second ground conductor. As can be seen, first column **401** comprises, in order from top to bottom, a first differential signal pair comprising signal conductors S**1**+ and S**1**–, a first ground conductor G, a second differential signal pair comprising signal conductors S**7**+ and S**7**–, and a second ground conductor G. Each of rows **413** and **416** comprises a plurality of ground conductors G. Rows **411** and **412** together comprise six differential signal pairs, and rows **514** and **515** together comprise another six differential signal pairs. The rows **413** and **416** of ground conductors limit cross talk between the signal pairs in rows **411**–**412** and the signal pairs in rows **414**–**415**. In the embodiment shown in FIG. **4**A, arrangement of 36 contacts into columns can provide twelve differential signal pairs. Because the connector is devoid of shields, the contacts can be made relatively larger (compared to those in a connector having shields). Therefore, less connector space is needed to achieve the desired impedance.

FIGS. **4**B and **4**C depict connectors according to the invention that include outer grounds. As shown in FIG. **4**B, a ground contact G can be placed at each end of each column. As shown in FIG. **4**C, a ground contact G can be placed at alternating ends of adjacent columns. It has been found that the placement of a ground contact G at alternating ends of adjacent columns results in a 35% reduction in NEXT and a 65% reduction in FEXT as compared to a connector having a contact arrangement that is otherwise the same, but which has no such outer grounds. It has also been found that basically the same results can be achieved through the placement of ground contacts at both ends of every contact column, as shown in FIG. **4**B. Consequently, it is preferred to place outer grounds at alternating ends of adjacent columns in order to increase contact density (relative to a connector in which outer grounds are placed at both ends of every column) without increasing the level of cross talk.

Alternatively, as shown in FIG. **5**, differential signal pairs may be arranged into rows. As shown in FIG. **5**, each row **511**–**516** comprises a repeating sequence of two ground conductors and a differential signal pair. First row **511** comprises, in order from left to right, two ground conductors G, a differential signal pair S**1**+, S**1**–, and two ground conductors G. Row **512** comprises in order from left to right, a differential signal pair S**2**+, S**2**–, two ground conductors G, and a differential signal pair S**3**+, S**3**–. The ground conductors block cross talk between adjacent signal pairs. In the embodiment shown in FIG. **5**, arrangement of 36 contacts into rows provides only nine differential signal pairs.

By comparison of the arrangement shown in FIG. **4**A with the arrangement shown in FIG. **5**, it can be understood that a column arrangement of differential signal pairs results in a higher density of signal contacts than does a row arrange-

ment. However, for right angle connectors arranged into columns, contacts within a differential signal pair have different lengths, and therefore, such differential signal pairs may have intra-pair skew. Similarly, arrangement of signal pairs into either rows or columns may result in inter-pair skew because of the different conductor lengths of different differential signal pairs. Thus, it should be understood that, although arrangement of signal pairs into columns results in a higher contact density, arrangement of the signal pairs into columns or rows can be chosen for the particular application.

Regardless of whether the signal pairs are arranged into rows or columns, each differential signal pair has a differential impedance Z_0 between the positive conductor Sx+ and negative conductor Sx− of the differential signal pair. Differential impedance is defined as the impedance existing between two signal conductors of the same differential signal pair, at a particular point along the length of the differential signal pair. As is well known, it is desirable to control the differential impedance Z_0 to match the impedance of the electrical device(s) to which the connector is connected. Matching the differential impedance Z_0 to the impedance of electrical device minimizes signal reflection and/or system resonance that can limit overall system bandwidth. Furthermore, it is desirable to control the differential impedance Z_0 such that it is substantially constant along the length of the differential signal pair, i.e., such that each differential signal pair has a substantially consistent differential impedance profile.

The differential impedance profile can be controlled by the positioning of the signal and ground conductors. Specifically, differential impedance is determined by the proximity of an edge of signal conductor to an adjacent ground and by the gap between edges of signal conductors within a differential signal pair.

Referring again to FIG. **4**A, the differential signal pair comprising signal conductors S**6**+ and S**6**− is located adjacent to one ground conductor G in row **413**. The differential signal pair comprising signal conductors S**12**+ and S**12**− is located adjacent to two ground conductors G, one in row **413** and one in row **416**. Conventional connectors include two ground conductors adjacent to each differential signal pair to minimize impedance matching problems. Removing one of the ground conductors typically leads to impedance mismatches that reduce communications speed. However, the lack of one adjacent ground conductor can be compensated for by reducing the gap between the differential signal pair conductors with only one adjacent ground conductor. For example, as shown in FIG. **4**A, signal conductors S**6**+ and S**6**− can be located a distance d_1 apart from each other and signal conductors S**12**+ and S**112**− can be located a different distance d_4 apart from each other. The distances may be controlled by making the widths of signal conductors S**6**+ and S**6**− wider than the widths of signal conductors S**12**+ and S**12**− (where conductor width is measured along the direction of the column).

For single ended signaling, single ended impedance can also be controlled by positioning of the signal and ground conductors. Specifically, single ended impedance is determined by the gap between a signal conductor and an adjacent ground. Single ended impedance is defined as the impedance existing between a signal conductor and ground, at a particular point along the length of a single ended signal conductor.

To maintain acceptable differential impedance control for high bandwidth systems, it is desirable to control the gap between contacts to within a few thousandths of an inch. Gap variations beyond a few thousandths of an inch may cause an unacceptable variation in the impedance profile; however, the acceptable variation is dependent on the speed desired, the error rate acceptable, and other design factors.

FIG. **6** shows an array of differential signal pairs and ground contacts in which each column of terminals is offset from each adjacent column. The offset is measured from an edge of a terminal to the same edge of the corresponding terminal in the adjacent column. The aspect ratio of column pitch to gap width, as shown in FIG. **6**, is P/X. It has been found that an aspect ratio of about 5 (i.e., 2 mm column pitch; 0.4 mm gap width) is adequate to sufficiently limit cross talk where the columns are also staggered. Where the columns are not staggered, an aspect ratio of about 8–10 is desirable.

As described above, by offsetting the columns, the level of multi-active cross talk occurring in any particular terminal can be limited to a level that is acceptable for the particular connector application. As shown in FIG. **6**, each column is offset from the adjacent column, in the direction along the columns, by a distance d. Specifically, column **601** is offset from column **602** by an offset distance d, column **602** is offset from column **603** by a distance d, and so forth. Since each column is offset from the adjacent column, each terminal is offset from an adjacent terminal in an adjacent column. For example, signal contact **680** in differential pair DP**3** is offset from signal contact **681** in differential pair DP**4** by a distance d as shown.

FIG. **7** illustrates another configuration of differential pairs wherein each column of terminals is offset relative to adjacent columns. For example, as shown, differential pair D**2** in column **701** is offset from differential pair D**1** in the adjacent column **702** by a distance d. In this embodiment, however, the array of terminals does not include ground contacts separating each differential pair. Rather, the differential pairs within each column are separated from each other by a distance greater than the distance separating one terminal in a differential pair from the second terminal in the same differential pair. For example, where the distance between terminals within each differential pair is Y, the distance separating differential pairs can be Y+X, where Y+X/Y>>1. It has been found that such spacing also serves to reduce cross talk.

EXEMPLARY CONNECTOR SYSTEMS ACCORDING TO THE INVENTION

FIG. **8** is a perspective view of a right angle electrical connector according to the invention that is directed to a high speed electrical connector wherein signal conductors of a differential signal pair have a substantially constant differential impedance along the length of the differential signal pair. As shown in FIG. **8**, a connector **800** comprises a first section **801** and a second section **802**. First section **801** is electrically connected to a first electrical device **810** and second section **802** is electrically connected to a second electrical device **812**. Such connections may be SMT, PIP, solder ball grid array, press fit, or other such connections. Typically, such connections are conventional connections having conventional connection spacing between connection pins; however, such connections may have other spacing between connection pins. First section **801** and second section **802** can be electrically connected together, thereby electrically connecting first electrical device **810** to second electrical device **812**.

As can be seen, first section **801** comprises a plurality of modules **805**. Each module **805** comprises a column of

conductors **830**. As shown, first section **801** comprises six modules **805** and each module **805** comprises six conductors **830**; however, any number of modules **805** and conductors **830** may be used. Second section **802** comprises a plurality of modules **806**. Each module **806** comprises a column of conductors **840**. As shown, second section **802** comprises six modules **806** and each module **806** comprises six conductors **840**; however, any number of modules **806** and conductors **840** may be used.

FIG. **9** is a side view of connector **800**. As shown in FIG. **9**, each module **805** comprises a plurality of conductors **830** secured in a frame **850**. Each conductor **830** comprises a connection pin **832** extending from frame **850** for connection to first electrical device **810**, a blade **836** extending from frame **850** for connection to second section **802**, and a conductor segment **834** connecting connection pin **832** to blade **836**.

Each module **806** comprises a plurality of conductors **840** secured in frame **852**. Each conductor **840** comprises a contact interface **841** and a connection pin **842**. Each contact interface **841** extends from frame **852** for connection to a blade **836** of first section **801**. Each contact interface **840** is also electrically connected to a connection pin **842** that extends from frame **852** for electrical connection to second electrical device **812**.

Each module **805** comprises a first hole **856** and a second hole **857** for alignment with an adjacent module **805**. Thus, multiple columns of conductors **830** may be aligned. Each module **806** comprises a first hole **847** and a second hole **848** for alignment with an adjacent module **806**. Thus, multiple columns of conductors **840** may be aligned.

Module **805** of connector **800** is shown as a right angle module. That is, a set of first connection pins **832** is positioned on a first plane (e.g., coplanar with first electrical device **810**) and a set of second connection pins **842** is positioned on a second plane (e.g., coplanar with second electrical device **812**) perpendicular to the first plane. To connect the first plane to the second plane, each conductor **830** turns a total of about ninety degrees (a right angle) to connect between electrical devices **810** and **812**.

To simplify conductor placement, conductors **830** can have a rectangular cross section; however, conductors **830** may be any shape. In this embodiment, conductors **830** have a high ratio of width to thickness to facilitate manufacturing. The particular ratio of width to thickness may be selected based on various design parameters including the desired communication speed, connection pin layout, and the like.

FIG. **10** is a side view of two modules of connector **800** taken along the corresponding line shown in FIG. **9**. FIG. **11** is a top view of two modules of connector **800** taken along the corresponding line shown in FIG. **9**. As can be seen, each blade **836** is positioned between two single beam contacts **849** of contact interface **841**, thereby providing electrical connection between first section **801** and second section **802** and described in more detail below. Connection pins **832** are positioned proximate to the centerline of module **805** such that connection pins **832** may be mated to a device having conventional connection spacing. Connection pins **842** are positioned proximate to the centerline of module **806** such that connection pins **842** may be mated to a device having conventional connection spacing. Connection pins, however, may be positioned at an offset from the centerline of module **806** if such connection spacing is supported by the mating device. Further, while connection pins are illustrated in the Figures, other connection techniques are contemplated such as, for example, solder balls and the like.

Returning now to illustrative connector **800** of FIG. **8** to discuss the layout of connection pins and conductors, first section **801** of connector **800** comprises six columns and six rows of conductors **830**. Conductors **830** may be either signal conductors S or ground conductors G. Typically, each signal conductor S is employed as either a positive conductor or a negative conductor of a differential signal pair; however, a signal conductor may be employed as a conductor for single ended signaling. In addition, such conductors **830** may be arranged in either columns or rows.

In addition to conductor placement, differential impedance and insertion losses are also affected by the dielectric properties of material proximate to the conductors. Generally, it is desirable to have materials having very low dielectric constants adjacent and in contact with as much as the conductors as possible. Air is the most desirable dielectric because it allows for a lightweight connector and has the best dielectric properties. While frame **850** and frame **852** may comprise a polymer, a plastic, or the like to secure conductors **830** and **840** so that desired gap tolerances may be maintained, the amount of plastic used is minimized. Therefore, the rest of connector comprises an air dielectric and conductors **830** and **840** are positioned both in air and only minimally in a second material (e.g., a polymer) having a second dielectric property. Therefore, to provide a substantially constant differential impedance profile, in the second material, the spacing between conductors of a differential signal pair may vary.

As shown, the conductors can be exposed primarily to air rather than being encased in plastic. The use of air rather than plastic as a dielectric provides a number of benefits. For example, the use of air enables the connector to be formed from much less plastic than conventional connectors. Thus, a connector according to the invention can be made lower in weight than convention connectors that use plastic as the dielectric. Air also allows for smaller gaps between contacts and thereby provides for better impedance and cross talk control with relatively larger contacts, reduces cross-talk, provides less dielectric loss, increases signal speed (i.e., less propagation delay).

Through the use of air as the primary dielectric, a lightweight, low-impedance, low cross talk connector can be provided that is suitable for use as a ball grid assembly ("BGA") right-angle connector. Typically, a right angle connector is "off-balance", i.e., disproportionately heavy in the mating area. Consequently, the connector tends to "tilt" in the direction of the mating area. Because the solder balls of the BGA, while molten, can only support a certain mass, prior art connectors typically are unable to include additional mass to balance the connector. Through the use of air, rather than plastic, as the dielectric, the mass of the connector can be reduced. Consequently, additional mass can be added to balance the connector without causing the molten solder balls to collapse.

FIG. **12** illustrates the change in spacing between conductors in rows as conductors pass from being surrounded by air to being surrounded by frame **850**. As shown in FIG. **12**, at connection pin **832** the distance between conductor S+ and S− is D**1**. Distance D**1** may be selected to mate with conventional connector spacing on first electrical device **810** or may be selected to optimize the differential impedance profile. As shown, distance D**1** is selected to mate with a conventional connector and is positioned proximate to the centerline of module **805**. As conductors S+ and S− travel from connection pins **832** through frame **850**, conductors S+, S− jog towards each other, culminating in a separation distance D**2** in air region **860**. Distance D**2** is selected to give

the desired differential impedance between conductor S+ and S−, given other parameters, such as proximity to a ground conductor G. The desired differential impedance Z_0 depends on the system impedance (e.g., first electrical device **810**), and may be 100 ohms or some other value. Typically, a tolerance of about 5 percent is desired; however, 10 percent may be acceptable for some applications. It is this range of 10% or less that is considered substantially constant differential impedance.

As shown in FIG. **13**A, conductors S+ and S− are positioned from air region **860** towards blade **836** and jog outward with respect to each other within frame **850** such that blades **836** are separated by a distance D**3** upon exiting frame **850**. Blades **836** are received in contact interfaces **841**, thereby providing electrical connection between first section **801** and second section **802**. As contact interfaces **841** travel from air region **860** towards frame **852**, contact interfaces **841** jog outwardly with respect to each other, culminating in connection pins **842** separated by a distance of D**4**. As shown, connection pins **842** are positioned proximate to the centerline of frame **852** to mate with conventional connector spacing.

FIG. **14** is a perspective view of conductors **830**. As can be seen, within frame **850**, conductors **830** jog, either inwardly or outwardly to maintain a substantially constant differential impedance profile along the conductive path.

FIG. **15** is a perspective view of conductor **840** that includes two single beam contacts **849**, one beam contact **849** on each side of blade **836**. This design may provide reduced cross talk performance, because each single beam contact **849** is further away from its adjacent contact. Also, this design may provide increased contact reliability, because it is a "true" dual contact. This design may also reduce the tight tolerance requirements for the positioning of the contacts and forming of the contacts.

As can be seen, within frame **852**, conductor **840** jogs, either inward or outward to maintain a substantially constant differential impedance profile and to mate with connectors on second electrical device **812**. For arrangement into columns, conductors **830** and **840** are positioned along a centerline of frames **850**, **852**, respectively.

FIG. **13**B is a cross-sectional view taken along line C—C of FIG. **13**A. As shown in FIG. **13**B, terminal blades **836** are received in contact interfaces **841** such that beam contacts **839** engage respective sides of blades **836**. Preferably, the beam contacts **839** are sized and shaped to provide contact between the blades **836** and the contact interfaces **841** over a combined surface area that is sufficient to maintain the electrical characteristics of the connector during mating and unmating of the connector.

As shown in FIG. **13**A, the contact design allows the edge-coupled aspect ratio to be maintained in the mating region. That is, the aspect ratio of column pitch to gap width chosen to limit cross talk in the connector, exists in the contact region as well, and thereby limits cross talk in the mating region. Also, because the cross-section of the unmated blade contact is nearly the same as the combined cross-section of the mated contacts, the impedance profile can be maintained even if the connector is partially unmated. This occurs, at least in part, because the combined cross-section of the mated contacts includes no more than one or two thickness of metal (the thicknesses of the blade and the contact interface), rather than three thicknesses as would be typical in prior art connectors (see FIG. **13**B, for example). Unplugging a connector such as shown in FIG. **13**B results in a significant change in cross-section, and therefore, a significant change in impedance (which causes significant degradation of electrical performance if the connector is not properly and completely mated). Because the contact cross-section does not change dramatically as the connector is unmated, the connector (as shown in FIG. **13**A) can provide nearly the same electrical characteristics when partially unmated (i.e., unmated by about 1–2 mm) as it does when fully mated.

FIG. **16**A is a perspective view of a backplane system having an exemplary right angle electrical connector in accordance with an embodiment of the invention. As shown in FIG. **16**A, connector **900** comprises a plug **902** and receptacle **1100**.

Plug **902** comprises housing **905** and a plurality of lead assemblies **908**. The housing **905** is configured to contain and align the plurality of lead assemblies **908** such that an electrical connection suitable for signal communication is made between a first electrical device **910** and a second electrical device **912** via receptacle **1100**. In one embodiment of the invention, electrical device **910** is a backplane and electrical device **912** is a daughtercard. Electrical devices **910** and **912** may, however, be any electrical device without departing from the scope of the invention.

As shown, the connector **902** comprises a plurality of lead assemblies **908**. Each lead assembly **908** comprises a column of terminals or conductors **930** therein as will be described below. Each lead assembly **908** comprises any number of terminals **930**.

FIG. **16**B is backplane system similar to FIG. **16**A except that the connector **903** is a single device rather than mating plug and receptacle. Connector **903** comprises a housing and a plurality of lead assemblies (not shown). The housing is configured to contain and align the plurality of lead assemblies (not shown) such that an electrical connection suitable for signal communication is made between a first electrical device **910** and a second electrical device **912**

FIG. **16**C is a board-to-board system similar to FIG. **16**A except that plug connector **905** is a vertical plug connector rather than a right angle plug connector. This embodiment makes electrical connection between two parallel electrical devices **910** and **913**. A vertical back-panel receptacle connector according to the invention can be insert molded onto a board, for example. Thus, spacing, and therefore performance, can be maintained.

FIG. **17** is a perspective view of the plug connector of FIG. **16**A shown without electrical devices **910** and **912** and receptacle connector **1100**. As shown, slots **907** are formed in the housing **905** that contain and align the lead assemblies **908** therein. FIG. **17** also shows connection pins **932**, **942**. Connection pins **942** connect connector **902** to electrical device **912**. Connection pins **932** electrically connect connector **902** to electrical device **910** via receptacle **1100**. Connection pins **932** and **942** may be adapted to provide through-mount or surface-mount connections to an electrical device (not shown).

In one embodiment, the housing **905** is made of plastic, however, any suitable material may be used. The connections to electrical devices **910** and **912** may be surface or through mount connections.

FIG. **18** is a side view of plug connector **902** as shown in FIG. **17**. As shown, the column of terminals contained in each lead assembly **908** are offset from one another column of terminals in an adjacent lead assembly by a distance D. Such an offset is discussed more fully above in connection with FIGS. **6** and **7**.

FIG. **19**A is a side view of a single lead assembly **908**. As shown in FIG. **19**A, one embodiment of lead assembly **908** comprises a metal lead frame **940** and an insert molded

plastic frame **933**. In this manner, the insert molded lead assembly **933** serves to contain one column of terminals or conductors **930**. The terminals may comprise either differential pairs or ground contacts. In this manner, each lead assembly **908** comprises a column of differential pairs **935**A and **935**B and ground contacts **937**.

As is also shown in FIG. **19**A, the column of differential pairs and ground contacts contained in each lead assembly **908** are arranged in a signal-signal-ground configuration. In this manner, the top contact of the column of terminals in lead assembly **908** is a ground contact **937**A. Adjacent to ground contact **937**A is a differential pair **935**A comprised of a two signal contacts, one with a positive polarity and one with a negative polarity.

As shown, the ground contacts **937**A and **937**B extend a greater distance from the insert molded lead assembly **933**. As shown in FIG. **19**B, such a configuration allows the ground contacts **937** to mate with corresponding receptacle contacts **1102**G in receptacle **1100** before the signal contacts **935** mate with corresponding receptacle contacts **1102**S. Thus, the connected devices (not shown in FIG. **19**B) can be brought to a common ground before signal transmission occurs between them. This provides for "hot" connection of the devices.

Lead assembly **908** of connector **900** is shown as a right angle module. To explain, a set of first connection pins **932** is positioned on a first plane (e.g., coplanar with first electrical device **910**) and a set of second connection pins **942** is positioned on a second plane (e.g., coplanar with second electrical device **912**) perpendicular to the first plane. To connect the first plane to the second plane, each conductor **930** is formed to extend a total of about ninety degrees (a right angle) to electrically connect electrical devices **910** and **912**.

FIGS. **20** and **21** are end and side views, respectively, of two columns of terminals in accordance with one aspect of the invention. As shown in FIGS. **20** and **21**, adjacent columns of terminals are staggered in relation to one another. In other words, an offset exists between terminals in adjacent lead assemblies. In particular and as shown in FIGS. **20** and **21**, an offset of distance d exists between terminals in column **1** and terminals in column **2**. As shown, the offset d runs along the entire length of the terminal. As stated above, the offset reduces the incidence of cross talk by furthering the distance between the signal carrying contacts.

To simplify conductor placement, conductors **930** have a rectangular cross section as shown in FIGS. **20** and **21**. Conductors **930** may, however, be any shape.

FIG. **22** is a perspective view of the receptacle portion of the connector shown in FIG. **16**A. Receptacle **1100** may be mated with connector plug **902** (as shown in FIG. **16**A) and used to connect two electrical devices (not shown). Specifically, connection pins **932** (as shown in FIG. **17**) may be inserted into aperatures **1142** to electrically connect connector **902** to receptacle **1100**. Receptacle **1100** also includes alignment structures **1120** to aid in the alignment and insertion of connector **900** into receptacle **1100**. Once inserted, structures **1120** also serve to secure the connector once inserted into receptacle **1100**. Such structures **1120** thereby prevent any movement that may occur between the connector and receptacle that could result in mechanical breakage therebetween.

Receptacle **1100** includes a plurality of receptacle contact assemblies **1160** each containing a plurality of terminals (only the tails of which are shown). The terminals provide the electrical pathway between the connector **900** and any mated electrical device (not shown).

FIG. **23** is a side view of the receptacle of FIG. **22** including structures **1120**, housing **1150** and receptacle lead assembly **1160**. As shown, FIG. **23** also shows that the receptacle lead assemblies may be offset from one another in accordance with the invention. As stated above, such offset reduces the occurrence of multi-active cross talk as described above.

FIG. **24** is a perspective view of a single receptacle contact assembly not contained in receptacle housing **1150**. As shown, the assembly **1160** includes a plurality of dual beam conductive terminals **1175** and a holder **1168** made of insulating material. In one embodiment, the holder **1168** is made of plastic injection molded around the contacts; however, any suitable insulating material may be used without departing from the scope of the invention.

FIG. **25** is a perspective view of a connector in accordance with another embodiment of the invention. As shown, connector **1310** and receptacle **1315** are used in combination to connect an electrical device, such as circuit board **1305** to a cable **1325**. Specifically, when connector **1310** is mated with receptacle **1315**, an electrical connection is established between board **1305** and cable **1325**. Cable **1325** can then transmit signals to any electrical device (not shown) suitable for receiving such signals.

In another embodiment of the invention, it is contemplated that the offset distance, d, may vary throughout the length of the terminals in the connector. In this manner, the offset distance may vary along the length of the terminal as well as at either end of the conductor. To illustrate this embodiment and referring now to FIG. **26**, a side view of a single column of right angle terminals is shown. As shown, the height of the terminals in section A is height H**1** and the height of the cross section of terminals in section B is height H**2**.

FIGS. **27** and **28** are end views of the columns of right angle terminals taken along the corresponding lines shown in FIG. **26**. In addition to the single column of terminals shown in FIG. **26**, FIGS. **27** and **28** also show an adjacent column of terminals contained in the adjacent lead assembly contained in the connector housing.

In accordance with the invention, the offset of adjacent columns may vary along the length of the terminals within the lead assembly. More specifically, the offset between adjacent columns varies according to adjacent sections of the terminals. In this manner, the offset distance between columns is different in section A of the terminals than in section B of the terminals.

As shown in FIGS. **27** and **28**, the cross sectional height of terminals taken along line A—A in section A of the terminal is H**1** and the cross sectional height of terminals in section B taken along line B—B is height H**2**. As shown in FIG. **27**, the offset of terminals in section A, where the cross sectional height of the terminal is H**1**, is a distance D**1**.

Similarly, FIG. **28** shows the offset of the terminals in section B of the terminal. As shown, the offset distance between terminals in section B of the terminal is D**2**. Preferably, the offset D**2** is chosen to minimize crosstalk, and may be different from the offset D**1** because spacing or other parameters are different. The multi-active cross talk that occurs between the terminals can thus be reduced, thereby increasing signal integrity.

In another embodiment of the invention, to further reduce cross talk, the offset between adjacent terminal columns is different than the offset between vias on a mated printed circuit board. A via is conducting pathway between two or more layers on a printed circuit board. Typically, a via is

created by drilling through the printed circuit board at the appropriate place where two or more conductors will interconnect.

To illustrate such an embodiment, FIG. **29** illustrates a front view of a cross section of four columns of terminals as the terminals mate to vias on an electrical device. Such an electric device may be similar to those as illustrated in FIG. **16**A. The terminals **1710** of the connector (not shown) are inserted into vias **1700** by connection pins (not shown). The connection pins, however, may be similar to those shown in FIG. **17**.

In accordance with this embodiment of the invention, the offset between adjacent terminal columns is different than the offset between vias on a mated printed circuit board. Specifically, as shown in FIG. **29**, the distance between the offset of adjacent column terminals is D**1** and the distance between the offset of vias in an electrical device is D**2**. By varying these two offset distances to their optimal values in accordance with the invention, the cross talk that occurs in the connector of the invention is reduced and the corresponding signal integrity is maintained.

FIG. **30** is a perspective view of a portion of another embodiment of a right angle electrical connector **1100**. As shown in FIG. **30**, conductors **930** are positioned from a first plane to a second plane that is orthogonal to the first plane. Distance D between adjacent conductors **930** remains substantially constant, even though the width of conductor **930** may vary and even though the path of conductor **930** may be circuitous. This substantially constant gap D provides a substantially constant differential impedance along the length of the conductors.

FIG. **31** is a perspective view of another embodiment of a right angle electrical connector **1200**. As shown in FIG. **12**, modules **1210** are positioned in a frame **1220** to provide proper spacing between adjacent modules **1210**.

FIG. **32** is a perspective view of an alternate embodiment of a receptacle connector **1100'**. As shown in FIG. **32**, connector **1100'** comprises a frame **1190** to provide proper spacing between connection pins **1175'**. Frame **1190** comprises recesses, in which conductors **1175'** are secured. Each conductor **1175'** comprises a single contact interface **1191** and a connection pin **1192**. Each contact interface **1191** extends from frame **1190** for connection to a corresponding plug contact, as described above. Each connection pin **1942** extends from frame **1190** for electrical connection to a second electrical device. Receptacle connector **1190** may be assembled via a stitching process.

To attain desirable gap tolerances over the length of conductors **903**, connector **900** may be manufactured by the method as illustrated in FIG. **33**. As shown in FIG. **33**, at step **1400**, conductors **930** are placed in a die blank with predetermined gaps between conductors **930**. At step **1410**, polymer is injected into the die blank to form the frame of connector **900**. The relative position of conductors **930** are maintained by frame **950**. Subsequent warping and twisting caused by residual stresses can have an effect on the variability, but if well designed, the resultant frame **950** should have sufficient stability to maintain the desired gap tolerances. In this manner, gaps between conductors **930** can be controlled with variability of tenths of thousandths of an inch.

Preferably, to provide the best performance, the current carrying path through the connector should be made as highly conductive as possible. Because the current carrying path is known to be on the outer portion of the contact, it is desirable that the contacts be plated with a thin outer layer of a high conductivity material. Examples of such high conductivity materials include gold, copper, silver, and tin alloy.

Connectors Having Contacts that May be Selectively Designated

FIGS. **34**A and **34**B depict example embodiments of a header assembly for a connector according to the invention. As shown, the header assembly **200** may include a plurality of insert molded lead assemblies (IMLAs) **202**. According to an aspect of the invention, an IMLA **202** may be used, without modification, for single-ended signaling, differential signaling, or a combination of single-ended signaling and differential signaling.

Each IMLA **202** includes plurality of electrically conductive contacts **204**. Preferably, the contacts **204** in each IMLA **202** form respective linear contact arrays **206**. As shown, the linear contact arrays **206** are arranged as contact columns, though it should be understood that the linear contact arrays could be arranged as contact rows. Also, though the header assembly **200** is depicted with 150 contacts (i.e., 10 IMLAs with 15 contacts per IMLA), it should be understood that an IMLA may include any desired number of contacts and a connector may include any number of IMLAs. For example, IMLAs having 12 or 9 electrical contacts are also contemplated. A connector according to the invention, therefore, may include any number of contacts.

The header assembly **200** includes an electrically insulating lead frame **208** through which the contacts extend. Preferably, the lead frame **208** is made of a dielectric material such as a plastic. According to an aspect of the invention, the lead frame **208** is constructed from as little material as possible. Otherwise, the connector is air-filled. That is, the contacts may be insulated from one another using air as a second dielectric. The use of air provides for a decrease in crosstalk and for a low-weight connector (as compared to a connector that uses a heavier dielectric material throughout).

The contacts **202** include terminal ends **210** for engagement with a circuit board. Preferably, the terminal ends are compliant terminal ends, though it should be understood that the terminals ends could be press-fit or any surface-mount or through-mount terminal ends. The contacts also include mating ends **212** for engagement with complementary receptacle contacts (described below in connection with FIGS. **35**A–B).

As shown in FIG. **34**A, a housing **214**A is preferred. The housing **214**A includes a first pair of end walls **216**A. FIG. **34**B depicts a header assembly with a peripheral shield assembly **214**B that includes a first pair of end walls **216**B and a second pair of end walls **218**B.

According to an aspect of the invention, the header assembly may be devoid of any internal shielding. That is, the header assembly may be devoid of any shield plates, for example, between adjacent contact arrays. A connector according to the invention may be devoid of such internal shielding even for high-speed, high-frequency, fast rise-time signaling.

Though the header assembly **200** depicted in FIGS. **34**A–B is shown for a right-angle connector, it should be understood that a connector according to the invention may be any style connector, such as a mezzanine connector, for example. That is, an appropriate header assembly may be designed according to the principles of the invention for any type connector.

FIGS. **35**A and **35**B depict an example embodiment of a receptacle assembly **220** for a connector according to the

invention. The receptacle assembly **220** includes a plurality of receptacle contacts **224**, each of which is adapted to receive a respective mating end **212**. Further, the receptacle contacts **224** are arranged in an arrangement that is complementary to the arrangement of the mating ends **212**. Thus, the mating ends **212** may be received by the receptacle contacts **224** upon mating of the assemblies. Preferably, to complement the arrangement of the mating ends **212**, the receptacle contacts **224** are arranged to form linear contact arrays **226**. Again, though the receptacle assembly **220** is depicted with 150 contacts (i.e., 15 contacts per column), it should be understood that a connector according to the invention may include any number of contacts.

Each receptacle contact **224** has a mating end **230**, for receiving a mating end **212** of a complementary header contact **204**, and a terminal end **232** for engagement with a circuit board. Preferably, the terminal ends **232** are compliant terminal ends, though it should be understood that the terminals ends could be press-fit, balls, or any surface-mount or through-mount terminal ends. A housing **234** is also preferably provided to position and retain the IMLAs relative to one another.

According to an aspect of the invention, the receptacle assembly may also be devoid of any internal shielding. That is, the receptacle assembly may be devoid of any shield plates, for example, between adjacent contact arrays.

FIG. **36** depicts an example embodiment of a connector according to the invention connecting signal paths between two circuit boards **240**A–B. Circuit boards **240**A–B may be mother and daughter boards, for example. In general, a circuit board **240**A–B may include one or more differential signaling paths, one or more single-ended signaling paths, or a combination of differential signaling paths and single-ended signaling paths. A signaling path typically includes an electrically conductive trace **242** that is electrically connected to an electrically conductive pad **244**. The terminals ends of the connector contacts are typically electrically coupled to the conductive pads (e.g., by soldering, BGA, press-fitting, or other techniques well-known in the art). If the circuit board is a multi-layer circuit board (as shown), the signaling path may also include an electrically conductive via **243** that extends through the circuit board.

Typically, a system manufacturer defines the signaling paths for a given application. According to an aspect of the invention, the same connector may be used, without structural modification, to connect either differential or single-ended signaling paths. According to an aspect of the invention, a system manufacturer may be provided with an electrical connector as described above (that is, an electrical connector comprising a linear array of contacts that may be selectively designated as either ground or signal contacts).

The system manufacturer may then designate the contacts as either ground or signal contacts, and electrically connect the connector to a circuit board. The connector may be electrically connected to the circuit board, for example, by electrically connecting a contact designated as a signal contact to a signaling path on the circuit board. The signaling path may be a single-ended signaling path or a differential signaling path. The contacts may be designated to form any combination of differential signal pairs and/or single-ended signal conductors.

FIG. **37** is a side view of an example embodiment of an IMLA **202** according to the invention. The IMLA **202** includes a linear contact array **206** of electrically conductive contacts **204**, and a lead frame **208** through which the contacts **204** at least partially extend. According to an aspect of the invention, the contacts **204** may be selectively designated as either ground or signal contacts. In a first designation, the contacts form at least one differential signal pair comprising a pair of signal contacts. In a second designation, the contacts form at least one single-ended signal conductor. In a third designation, the contacts form at least one differential signal pair and at least one single-ended signal conductor.

FIGS. **38**A–**38**C depict example contact designations for an IMLA such as depicted in FIG. **37**. As shown in FIG. **38**A, contacts b, c, e, f, h, i, k, l, n, and o, for example, may be defined to be signal contacts, while contacts a, d, g, j, and m, for example, may be defined to be ground contacts. In such a designation, signal contact pairs b-c, e-f, h-i, k-l, and n-o form differential signal pairs. As shown in FIG. **38**B, contacts b, d, f, h, j, l, and n, for example, may be defined to be signal contacts, while contacts a, c, e, g, i, k, m, and o, for example, may be defined to be ground contacts. In such a designation, signal contacts b, d, f, h, j, l, and n form single-ended signal conductors. As shown in FIG. **38**C, contacts b, c, e, f, h, j, l, and n, for example, may be defined to be signal contacts, while contacts a, d, g, i, k, m, and o, for example, may be defined to be ground contacts. In such a designation, signal contact pairs b-c and e-f form differential signal pairs, and signal contacts h, j, l, and n form single-ended signal conductors. It should be understood that, in general, each of the contacts may thus be defined as either a signal contact or a ground contact depending on the requirements of the application.

In each of the designations depicted in FIGS. **38**A–**38**C, contacts g and m are ground contacts. As discussed in detail above, it may be desirable, though not necessary, for ground contacts to extend further than signal contacts. This may be desired so that the ground contacts make contact before the signal contacts do, thus bringing the system to ground before the signal contacts are mated. Because contacts g and m are ground contacts in either designation, the terminal ends of ground contacts g and m may be extended beyond the terminal ends of the other contacts so that the ground contacts g and m mate before any of the signal contacts mate and, still, the IMLA can support either designation without modification.

FIG. **39** is a side view of another example embodiment of an insert molded lead assembly according to the invention. FIGS. **40**A–**40**C depict example contact designations for an IMLA such as depicted in FIG. **39**.

As shown in FIG. **40**A, contacts a, b, d, e, g, h, j, k, m, and n, for example, may be defined to be signal contacts, while contacts c, f, i, l, and o, for example, may be defined to be ground contacts. In such a designation, signal contact pairs a-b, d-e, g-h, j-k, and m-n form differential signal pairs. As shown in FIG. **40**B, contacts a, c, e, g, i, k, and m, and o for example, may be defined to be signal contacts, while contacts b, d, f, h, j, l, and n, for example, may be defined to be ground contacts. In such a designation, signal contacts a, c, e, g, i, k, and m, and o form single-ended signal conductors. As shown in FIG. **40**C, contacts a, c, e, g, h, j, k, m, and n, for example, may be defined to be signal contacts, while contacts b, d, f, i, l, and o, for example, may be defined to be ground contacts. In such a designation, signal contacts a, c, and e form single-ended signal conductors, and signal contact pairs g-h, j-k, and m-n form differential signal pairs. Again, it should be understood that, in general, each of the contacts may thus be defined as either a signal contact or a ground contact depending on the requirements of the application. In each of the designations depicted in FIGS. **40**A–**40**C, contacts f and l are ground contacts, the terminals ends of which may extend beyond the terminal ends of the

other contacts so that the ground contacts f and l mate before any of the signal contacts mate.

The contact array may configured such that a desired impedance between contacts is achieved, and such that insertion loss and cross-talk are limited to acceptable levels—even in the absence of shield plates between adjacent IMLAs. Further, because desired levels of impedance, insertion loss, and cross-talk may be achieved within a single IMLA even in the absence of shields, a single IMLA may function as a connector system independently of the presence or absence of adjacent IMLAs, and independently of the designation of any adjacent IMLAs. In other words, an IMLA according to the invention does not require adjacent IMLAs to function properly.

Though the present invention provides for lightweight, high contact density connectors, contact density may be sacrificed in instances where manufacturing costs or specific product requirements negate the need for high density. Because an IMLA according to the invention does not require adjacent IMLAs to function properly, IMLAs may be spaced relatively closely together or relatively far apart from one another without a significant reduction in performance. Greater IMLA spacing facilitates the use of larger diameter contact wires, which are easier to make and manipulate using known automated production processes.

FIG. **41** depicts a contact arrangement for an adjacent pair of IMLAs **11**, **12** wherein the contacts are defined to form a respective plurality of differential signal pairs in each IMLA. For purposes of this description, the linear contact arrays **246**A and **246**B may be considered contact columns. The rows are referred to as A-O. Signal contacts are designated by the letter of the corresponding row; ground contacts are designated by GND. As shown, contacts **1**A and **1**B form a pair, contacts **2**B and **2**C form a pair, etc.

A number of parameters may be considered in determining a suitable contact array configuration for an IMLA according to the invention. For example, contact thickness and width, gap width between adjacent contacts, and adjacent contact coupling may be considered in determining a suitable contact array configuration that provides acceptable or optimal levels of impedance, insertion loss, and cross-talk, without the need for shields between adjacent contact arrays, in an IMLA that may be designated as differential, single-ended, or a combination of both. Issues relating to the consideration of these and other such parameters are described in detail above. Though it should be understood that such parameters may be tailored to fit the needs of a particular connector application, an example connector according to the invention will now be described to provide example parameter values and performance data obtained for such a connector.

In an embodiment of the invention, each contact may have a contact width W of about one millimeter, and contacts may be set on 1.4 millimeter centers C. Thus, adjacent contacts may have a gap width GW between them of about 0.4 millimeters. The IMLA may include a lead frame into or through which the contacts extend. The lead frame may have a thickness T of about 0.35 millimeters. An IMLA spacing IS between adjacent contact arrays may be about two millimeters. Additionally, the contacts may be edge-coupled along the length of the contact arrays, and adjacent contact arrays may be staggered relative to one another.

Generally, the ratio W/GW of contact width W to gap width GW between adjacent contacts will be greater in a connector according to the invention than in prior art connectors that require shields between adjacent contact arrays. Such a connector is described in published U.S. patent application 2001/0005654A1. Typical connectors, such as those described in application 2001/0005654, require the presence of more than one lead assembly because they rely on shield plates between adjacent lead assemblies. Such lead assemblies typically include a shield plate disposed along one side of the lead frame so that when lead frames are placed adjacent to one another, the contacts are disposed between shield plates along each side. In the absence of an adjacent lead frame, the contacts would be shielded on only one side, which would result in unacceptable performance.

Because shield plates between adjacent contact arrays are not required in a connector according to the invention (because, as will be explained in detail below, desired levels of cross-talk, impedance, and insertion loss may be achieved in a connector according to the invention because of the configuration of the contacts), an adjacent lead assembly having a complementary shield is not required, and a single lead assembly may function acceptably in the absence of any adjacent lead assembly.

FIG. **42**A provides a reflection plot of differential impedance as a function of signal propagation time through each of the differential signal pairs shown in FIG. **41**. Differential impedance was measured for each signal pair at various times as a signal propagated through a first test board, associated header vias, the signal pair, associated receptacle vias, and a second test board. As shown, each differential signal pair has a differential impedance of about 90–110 ohms, and the differential impedance is relatively constant (i.e., +/−about 5 ohms over the length of the connector) through each of the signal pairs. A differential impedance of about 92–108 ohms is preferred The impedance profile for each signal pair is about the same as the impedance profile for every other signal pair. Differential impedance was measured for a 40 ps rise time from 10%–90% of signal level.

FIG. **42**B provides a plot of insertion loss as a function of signal frequency for each of the differential signal pairs shown in FIG. **41**. As shown, insertion loss is relatively constant (less than about −2 dB) for signals up to 10 GHz, and insertion loss for each pair was about the same as the insertion loss for every other pair.

FIGS. **42**C and **42**D provide, respectively, worst case measurements of multi-active near-end and far-end crosstalk as measured at each of the signal pairs. The cross-talk was measured for 40 and 100 ps rise times from 10%–90% of signal level.

FIG. **43** depicts a contact arrangement for an adjacent pair of IMLAs wherein the contacts are defined to form a respective plurality of single-ended signal conductors in each IMLA. The IMLAs are the same as those depicted in FIG. **41**, the only difference being the contact definitions. Again, the linear contact arrays **246**A and **246**B may be considered contact columns, and the rows are referred to as A–O. Signal contacts are designated by the letter of the corresponding row; ground contacts are designated by GND. As shown, contacts **1**A, **2**B, **1**C, etc., are single-ended signal conductors.

FIG. **44**A provides a reflection plot of single-ended impedance as a function of signal propagation time through each of the signal contacts shown in FIG. **43**. Single-ended impedance was measured for each signal contact at various times as a signal propagated through a first test board, an associated header via, the signal contact, an associated receptacle via, and a second test board. As shown, each single-ended signal conductor has a single-ended impedance of about 40–70 ohms, and the single-ended impedance is

relatively constant (i.e., +/−about 10 ohms over the length of the connector) through each of the signal contacts. A single-ended impedance of about 40–60 ohms is preferred. The impedance profile for each signal contact is about the same as the impedance profile for every other signal contact. Single-ended impedance was measured for a 40 ps rise time from 10%–90% of signal level.

FIG. **44**B provides a reflection plot of single-ended impedance as a function of signal propagation time through each of the signal contacts shown in FIG. **43** measured for a 150 ps rise time from 20%–80% of signal level.

FIG. **44**C provides a plot of insertion loss as a function of signal frequency for each of the signal contacts shown in FIG. **43**. As shown, insertion loss is relatively constant (less than about −2 dB) for signals up to about four GHz, and insertion loss for each contact was about the same as the insertion loss for every other contact.

FIGS. **44**D and **44**E provide, respectively, worst case measurements of multi-active near-end and far-end crosstalk as measured at each of the signal contacts. The cross-talk was measured for a 150 ps rise time from 20% to 80% of signal level.

FIGS. **45**A–**45**F provide cross-talk measurements for a single-ended aggressor injecting noise onto a differential pair. Signal contacts are designated by the letter of the corresponding row; pairs are surrounded by boxes. Ground contacts are designated by GND. For each differential pair in each array, half of the pair was driven (i.e., contacts B, E, H, K, and N). The near-end and far-end differential noise voltage was measured on the adjacent pair. The non-driven half of the aggressor pair was terminated in 50 ohms. Cross-talk percentages are shown for rise-times of 40 ps (10%–90%), 100 ps (10%–90%), and 150 ps (20%–80%). The numbers shown indicate the percentage of the single-ended signal voltage that would show up as differential noise on the adjacent differential pair.

FIGS. **46**A–**46**F provide cross-talk measurements for a differential pair aggressor injecting noise onto a single-ended contact. Again, signal contacts are designated by the letter of the corresponding row, and ground contacts are designated by GND. For each differential pair in each array, the pair was driven, and the near-end single-ended voltage was measured on one half of an adjacent pair (i.e., contacts B, E, H, K, and N). The unused half of the victim pair was terminated in 50 ohms. Cross-talk percentages are shown for rise-times of 40 ps (10%–90%), 100 ps (10%–90%), and 150 ps (20%–80%). The numbers shown indicate the percentage of the differential signal voltage that would show up as single-ended noise on an adjacent single-ended contact.

In summation, the present invention can be a scalable, inverse two-piece backplane connector system that is based upon an IMLA design that can be used for either differential pair or single ended signals within the same IMLA. The column differential pairs demonstrate low insertion loss and low cross-talk from speeds less than approximately 2.5 Gb/sec to greater than approximately 12.5 Gb/sec. Exemplary configurations include 150 position for 1.0 inch slot centers and **120** position for 0.8 slot centers, all without interleaving shields. The IMLAs are stand-alone, which means that the IMLAs may be stacked into any centerline spacing required for customer density or routing considerations. Examples include, but are certainly not limited to, 2 mm, 2.5 mm, 3.0 mm, or 4.0 mm. By using air as a dielectric, there is improved low-loss performance. By taking further advantage of electromagnetic coupling within each IMLA, the present invention helps to provide a shieldless connector with good signal integrity and EMI performance. The stand alone IMLA permits an end user to specify whether to assign pins as differential pair signals, single ended signals, or power. At least eighty Amps of capacity can be obtained in a low weight, high speed connector.

It is to be understood that the foregoing illustrative embodiments have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the invention. Words which have been used herein are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular structure, materials and/or embodiments, the invention is not intended to be limited to the particulars disclosed herein. Rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the teachings of this specification, may affect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects.

What is claimed is:

1. An electrical connector, comprising:

a first row of electrical contacts, comprising a first differential signal pair, the first differential signal pair comprising two broadside-coupled electrical signal contacts positioned along a first row centerline and on opposite sides of a first column centerline, the first column centerline positioned perpendicular to the first row centerline;

a second differential signal pair comprising two broadside coupled electrical signal contacts positioned on opposite sides of a second column centerline, the second column centerline positioned parallel to the first column centerline and perpendicular to the first row centerline;

a third differential signal pair comprising two broadside-coupled electrical signal contacts that are positioned on opposite sides of a third column centerline, the third column centerline positioned parallel to the second column centerline and perpendicular to the first row centerline;

wherein (i) the first column centerline is adjacent to the second column centerline and the second column centerline is adjacent to the third column centerline, (ii) the first, second, and third differential signal pairs are evenly spaced apart by a fixed column-spacing distance measured from the first column centerline to the second column centerline; (iii) a fixed gap distance is defined between the respective two broadside coupled electrical contacts that form each of the first, second and third differential signal pairs; (iv) an aspect ratio of the fixed column-spacing distance to the fixed gap distance is approximately eight to ten; (v) a differential impedance of the differential signal pairs is matched to a system impedance, plus or minus ten ohms, at data transfer rates of 1 Gigabit/sec and 10 Gigabits/sec; and (vi) the electrical connector is devoid of shields between the first differential signal pair and the second differential signal pair.

2. The electrical connector of claim **1**, wherein each of the electrical contacts terminates with a respective fUsible mounting element.

3. The electrical connector of claim **1**, wherein the system impedance is 100 Ohms.

4. The electrical connector of claim **1**, wherein the first row of electrical contacts further comprises a fourth differential signal pair, the fourth differential signal pair compris-

ing two broadside coupled electrical contacts positioned on opposite sides of the third column centerline.

5. The electrical connector of claim **1**, further comprising a first pair of elongated ground contacts positioned along the first column centerline and a second pair of elongated ground contacts positioned along the third column centerline, the first pair of elongated ground contacts comprising two electrical contacts positioned broadside-to-broadside on opposite sides of the first column centerline and the second pair of electrical ground contacts positioned broadside-to-broadside on opposite sides of the third column centerline.

6. The electrical connector of claim **1** wherein the electrical connector is devoid of shields between the second differential signal pair and the third differential signal pair.

7. The electrical connector of claim **6**, further comprising three broadside coupled differential signal pairs positioned along the first column centerline, three broadside coupled differential signal pairs positioned along the second column centerline, and three broadside coupled differential signal pairs positioned along the third column centerline, wherein one of the three differential signal pairs positioned along the second column centerline is a victim pair, and differential signals with rise times of forty picoseconds in six differential signal pairs positioned along the first, second, and third column centerlines that are closest to the victim pair produce no more than six percent worst-case, multi-active cross talk on the victim pair.

8. The electrical connector of claim **1**, wherein the fixed gap distance is approximately 0.3mm to 0.4mm.

9. The electrical connector of claim **8**, wherein an air dielectric is present between the respective two broadside coupled electrical contacts that define the fixed gap distance.

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