

MULTI-CHANNEL INDIVIDUALLY DEFINED CONTROLLED IMPEDANCE CONNECTOR

Field of the Invention

[0001] The present invention relates to electrical signal interconnect system used for coupling signals between circuit assemblies, and more particularly, high-frequency connectors with multiple transmission channels comprising pre-fabricated pogo or connector pins coated with dielectric sleeves for providing signal connectivity, shielding and impedance matching for individual channels.

Background of the Invention

[0002] High performance connectors designed for electronic modules and assemblies are essential components in many design, testing and production applications. The choice of high frequency connectors is limited. Some popular configurations include BNC, N and sub-miniature type RF connectors. Whilst smaller RF connectors such as SMA, SMB and SMC allow more input-output connections per unit area or volume, they are not sufficiently compact, low cost and flexible for many applications. The controlled impedance connector assembly of the present invention provides compact and inexpensive multi-channel connection. Furthermore, the characteristic impedance of each channel can easily be defined and changed by plugging or inserting suitable pre-fabricated receptacles or pogo pins coated with dielectric sleeves into the corresponding solder or pogo-pin type connectors.

[0003] Solder type connectors have widely been used, especially in computer and audio equipments. The controlled impedance connector of the present invention can be configured as solder type connectors for high-density I/O connection of high frequency analogue and digital signals. Furthermore, the present connect system can be configured as pogo pin connectors, which are well suited for applications requiring short set-up time, high reliability and relatively long usage cycle. Pogo pins are good electrical conductors and they play a critical role in determining the overall electrical performance of said connectors. As shown in **FIG. 1a**, a conventional connector assembly **100** comprises a plurality of pogo pins **110** housed in cavities **121** of electrically insulating slab **120** which

provides positional alignment, mechanical support and electrical insulation to said pogo pins. Each pogo pin primarily comprises one (single-ended) or two (double-ended) plungers 112 resting on a spring housed inside a barrel 111. When source circuit board 130 and target circuit board 140 compress on the pogo pins 110 of said connector 100 in the directions 190, said pogo pins 110 complete the paths for electrical connection between source terminals 131 and the corresponding target terminals 141. FIG. 1b shows the top view of the pogo pins housed in insulating slab 120. Said multi-channel connector 100 provides electrical connectivity, without the need for soldering or crimping, between source and target systems capable of board, module or component level testing, product development, software downloading or the like. Each connector channel 150 provides single electrical conductivity path similar to a plated through hole used on printed circuit boards. The required number of channels depends on the total number of input-output count, test points, power and ground pads. Over the past decade, probe designers have made considerable advance in designing pogo pins of high electrical conductivity, good resilience and mechanical strength to meet the increasing requirements for shorter turn-around time, higher reliability and longer usage cycle. In addition to the above-named challenges, high-frequency connectors must meet the increasing bandwidth requirements as a result of the trend towards employing higher processing speed, higher frequency RF front-ends for miniaturization and portability, and wider signal spectrum to achieve higher transceiver sensitivity. Conventional connector designs 100 may result in poor signal integrity when handling high frequency analogue and digital signals. The impedance looking into the input-output terminals 131, 141 of said source and target boards ranges typically between 50 ohms and 100 ohms. When a high-frequency signal travels into or out of an input-output terminal, a portion of said signal is reflected at the interface between source / target board 130 / 140 and the corresponding connector channel 150 unless said channel has an impedance matched to the impedance of said terminal. Said reflected signal not just causes return loss but also leads to undesirable signal coupling and interference within the source and target systems 130, 140. The reflections are quantified by the S_{11} and S_{22} parameters which are typically frequency dependent. Return loss leads to attenuation whereas poor frequency response causes signal distortion and they may cause high false reject rate in a manufacturing line. Signal cross-talk is another drawback associated with using conventional connector designs 100 at the higher end of the frequency spectrum.

When the frequencies of a signal and its harmonics are high, unwanted radiation and mutual coupling among signals traveling along pogo pins 110 can cause higher bit error rate and lower transceiver sensitivity. The common practice today is employ short pogo pins down to 2mm in length such that the adverse effect of electrical discontinuity is reduced. However shorter pins are costly and they may not adequately accommodate to the non-planarity of the source and target boards, which may lead to inconsistent performance especially after prolonged use. Furthermore, signal cross-talk remains significant particularly for pins without ground fence. Patent application US2003/0027423A1 discloses short contact structures having probe tips and resilient means produced by photo-etching technique. In patent US5166605, a load card with striplines in a fan-out configuration is used to interconnect devices to a load system. Unwanted signal interference is inevitable unless all striplines carrying high-frequency signals are properly shielded, and this implies the use of printed circuit board comprising a large number of layers. Furthermore, said load card is limited to interconnecting a specific model of devices which have identical profile of impedance values across all the input-output pins.

[0004] Accordingly, there is an imperative need for an interconnect system capable of supporting the highest signal and harmonic frequency in accordance with design requirements, and suppressing signal cross talk and interference typically experienced in conventional connector designs. There is a further need for a connector design capable of interconnecting multiple models of source devices having different input-output impedance profiles.

Summary of the Invention

[0005] The connector design in the present invention comprises multiple transmission channels having pre-fabricated receptacles or pogo pins coated with dielectric sleeves for providing signal connectivity, shielding and impedance matching for individual channels, with the objectives of providing maximum signal power transfer and shielding against unwanted mutual coupling.

[0006] According to one aspect of the present invention, said connector comprises a plurality of transmission channels disposed in an electrically conductive slab, and each said channel comprises a receptacle or pogo pin coated or wrapped by at least one concentric layer of low-loss dielectric sleeve disposed along the longitudinal axis of a

cylindrical cavity. The dimensions and the dielectric characteristics of said dielectric sleeve are chosen to yield the matching characteristics impedance in accordance with design requirements. Coated receptacles are designed to couple with the corresponding male connector pins whereas coated pogo pins are used to complete the electrical paths between two printed circuit boards or systems.

[0007] According to another aspect of the present invention, the characteristic impedance of said channel is approximated by the characteristic impedance expressions of equivalent coaxial transmission lines.

[0008] According to yet another aspect of the present invention, a method for implementing controlled impedance transmission channels capable of providing shielding against unwanted mutual coupling is disclosed. A method of providing means of adjusting channel impedance using pre-fabricated receptacles and pogo pins coated with low-loss concentric dielectric sleeves having predetermined dielectric characteristics and dimensions is also disclosed.

[0009] The multi-channel controlled impedance connector in the present invention has the added advantage that it can be machined to the exact dimensions of existing connector designs for direct replacement.

Brief Description of the Drawings

[0010] Preferred embodiments according to the present invention will now be described with reference to the figures, in which like reference numerals denote like elements.

[0011] **FIGS. 1a & 1b** illustrate respectively the cross-sectional side and top views of a conventional pogo-pin connector.

[0012] **FIGS. 2a & 2b** show respectively the cross-sectional views of the controlled impedance pogo-pin connector before and after said connector has coupled to both source and target systems.

[0013] **FIG. 3** shows individual pre-fabricated coated pogo pins of the present invention.

[0014] **FIG. 4** shows individual pre-fabricated coated receptacles of the present invention.

[0015] **FIGS. 5a & 5b** illustrate respectively the side views of the controlled impedance female solder type connector having coated receptacles before and after coupling to a corresponding male solder type connector

Detailed Description of the Invention

[0016] **FIG. 2a** illustrates the cross-sectional view of the multi-channel controlled impedance connector of the present invention. An array of transmission channels **250** is disposed in an electrically conductive slab **220** and each of said channels comprises a cylindrical cavity **221**. Said cavity **221** further houses a pogo pin **110** having its barrel **111** fully enclosed by dielectric coating or sleeve **210** for a single-layer configuration and by concentric dielectric layers **211** & **212** for a two-layer design. The end plungers **112** of said pogo pin emerge out of said conductive slab **220** through the openings at both ends of said cavity **221**. The choice of thickness and the effective dielectric constant of said dielectric sleeve are essential to achieving matched impedance. Conductive slab **220** is made entirely from or coated with good electrical conductor at the highest signal frequency of interest. Ground terminals **260** of source board **130** and target board **140** are suitably positioned around their corresponding input-output terminals **131** such that said ground terminals **260** come in alignment and contact with conductive slab **220** when the signal terminals of both source board **130** and target board **140** are in electrical contact with the corresponding pogo pins **110**. **FIG. 2b** illustrates said alignment of source and target signal and ground terminals. The pogo probes **110** are made from gold-plated beryllium copper or any other suitable electrical conducting material and they have two end plungers **112** or they could be single ended (not shown). The plunger tips could be shaped in a variety of ways for different mechanical and electrical requirements. Said tip shape includes but is not limited to flat, round-edged, convex, concave and faceted. The distribution of pogo probes in the connector is determined by the terminal configuration of said source and target boards **130**, **140**.

[0017] **FIG. 3** illustrates individual pogo pins pre-coated with single-layered **290** or multilayer **291** dielectric sleeves. Each coated pogo pin exhibits predetermined characteristic impedance when inserted into a channel cavity **221**. The impedance $Z_{o, ch}$ of each channel is approximated by the square-root of the ratio of inductance per meter length L_{ch} divided by capacitance per meter length C_{ch} , where inductance $L_{ch} \propto \log (d_{cavity} /$

$d_{\text{conductor}}$) with d_{cavity} **215** and $d_{\text{conductor}}$ **213** denoting cross-sectional diameters of cavity **221** and probe barrel **111**. The length of channel has no effect on its characteristic impedance and cavities of smaller diameters give higher impedance values. For single-layered sleeves with relative dielectric constant ϵ_r , the channel characteristic impedance $Z_{o,\text{ch}} = 138 \log (d_{\text{cavity}} / d_{\text{conductor}}) / \epsilon_r^{0.5}$, which is essentially the characteristic impedance expression for coaxial cables. Since high-frequency signals tend to propagate on the surface or skin of a conductor, the non-solid construction of pogo pins does not cause significant signal attenuation. With the diameter of pogo probe barrel kept unchanged, impedance matching is simply achieved by choosing an appropriate value for the cavity diameter and dielectric constant ϵ_r . For materials having relative dielectric constant close to one (i.e. free air spacer), the cut-off frequency $f_c = 7.512 / (d_{\text{cavity}} + d_{\text{conductor}})$. In order to match a 50-ohm terminal, a ratio of $d_{\text{cavity}} / d_{\text{conductor}} = 2.3$ is used, and suppose the diameter of pogo pins used is 1.5mm, then the cavity diameter should be machined to 3.5mm. For the values of diameters chosen, the connector would have a cut-off frequency of 1.5GHz. There is virtually little restriction on the length of pogo pins used as long as the signal attenuation across said pogo pins is insignificant.

[0018] For channels using two-layered dielectric sleeves with the inner dielectric layer having outer diameter D_{sleeve1} **214** and dielectric constant ϵ_{r1} , and with the outer dielectric layer having dielectric constant ϵ_{r2} , the corresponding channel characteristic impedance $Z_{o,\text{ch}} = \mu_o / (2\pi) \sqrt{\{\ln(D_{\text{cavity}}/D_{\text{conductor}})[\ln(D_{\text{cavity}}/D_{\text{sleeve1}})/\epsilon_{r2} + \ln(D_{\text{sleeve1}}/D_{\text{conductor}})/\epsilon_{r1}]\}}$ where μ_o is the permeability of free space. The total number of concentric layers used can exceed two and is only limited by the volume between pogo pins and corresponding cavity walls. For a channel using pogo pin coated with two layers of concentric dielectric materials with the outer layer having relative dielectric constant close to one and an inner layer having dielectric constant greater than one, the resultant channel impedance is inversely proportional to the outer diameter of said inner layer. This provides a convenient channel impedance tuning means wherein possible discrepancies from the desired goals can be offset. Said discrepancies are mostly due to mechanical tolerance of machined parts and pogo pins.

[0019] Referring to **FIG. 4**, the same dielectric sleeves **210**, **211** & **212** can be employed to wrap around cylindrical female connector sleeves or receptacles **410** having the same external diameter **213** as the external barrel diameter of the pogo pins in **FIGS. 2**

& 3. Receptacles 410 are good electrical conductors having a first end 411 flush with dielectric sleeves 210, 211 & 212 and a second non-mating end 412 emerged from said dielectric sleeves for soldering onto a source board. Coated receptacles 402 & 404 are pre-fabricated parts for use in female solder type connectors having electrically conducting slab 220 with channel cavities 221 as shown in FIG. 5a. Since the corresponding dielectric and conductor diameters are identical between the coated pogo pins 290, 291 in FIG. 3 and the coated receptacles 402, 404 in FIG. 4, the channel characteristic impedance expressions and cut-off frequency derived above for pogo-pin connectors 200 are applicable to the solder type connectors 510, with the diameter variable $D_{\text{conductor}} = D_{\text{receptacle}}$ (213).

[0020] Referring to FIG. 5a, said first ends 411 of coated receptacles 410 are flush with electrically conducting slab 220 of the female solder type connector 510. Said second non-mating ends 412 of coated receptacles 410 are inserted into (518) source system board 130 for soldering to pads 131. The corresponding male solder type connector 520 comprises male pins 420 disposed partially inside an enclosure 522 with a front-side opening 526. Said enclosure 522 is shaped to slide onto and wrap around slab 220 of the female connector 510. Said male pins 420 have first ends 421 disposed inside said enclosure 522 and second non-mating ends 422 emerged out of said enclosure 522 for insertion into (528) target system board 140 for soldering to electrically conducting pads 112. A layer of electrical insulation 524 provides said male pins 420 with the mechanical support and electrical insulation. FIG. 5b illustrates male solder type connector 520 mated or coupled to female solder type connector 510, with male pins 420 inserted into the corresponding coated receptacles 410, enclosure 522 slid over slab 220 and the ground pads 260 on the source system board 130 electrically coupled to said slab 220. All said male pins 420 and receptacles 410 are soldered (530) onto the respective pads 131, 112.

[0021] The connector designs of the present invention have made it possible for users to easily configure a multi-channel connector with pre-fabricated receptacles or pogo pins coated with concentric dielectric sleeves having predetermined dielectric constants and dimensions to achieve a required profile of channel characteristic impedance values when said coated receptacles or pogo pins are inserted into the corresponding channels of the conductive slab 220. Said coated receptacles and pogo pins are removable and interchangeable which allow easy impedance matching as per design requirements.

[0022] The controlled impedance pogo-pin connector of the present invention should structurally be distinguished from the pogo pin configuration of conventional connector assemblies **100** (**FIG. 1**), which use insulator **120** instead of conductive slabs **220** to house pogo pins; and secondly, pogo pins in said conventional designs are held tightly against cavity walls **121** of said insulator block without any use of dielectric sleeves or spacers. The present invention provides a solution to three major problems associated with high-frequency interconnect systems. Firstly, the impedance of *individual* channel can be designed or tuned to match those of the source and target boards by choosing appropriate diameters for both cavities **221** and pogo pins **110** encased by suitable dielectric sleeve or coating. However pogo pins of larger cross-sectional area should be used for power and ground terminals. Secondly, the grounded conductive slab **220** has an important added advantage of providing excellent shielding essential to the suppression of cross talks and interference when high-frequency signals propagate along pogo pins **110**. Thirdly, coated pogo pins **290**, **291** are removable and interchangeable which allow easy impedance matching for source and target systems of different input-output impedance profiles.

[0023] The multi-channel controlled impedance connectors **200**, **510** & **520** in the present invention provide a low-cost yet effective solution to the classic problems of interface impedance mismatch *and* unwanted signal radiation causing mutual-coupling leading to cross talks, adjacent-channel interference, inter-modulation, amplitude and phase distortion and the like. Secondly, the connector designs in the present invention have the added advantage that they can be machined to the exact dimensions of existing connector designs for direct replacement without the need for extensive modification of existing devices. In addition, the controlled impedance pogo pin connector of present invention does not require the use of very short pogo pins which are costly, and they entail high level of terminal planarity of source and target boards, and pose space-related constraints when designing said circuit boards.

[0024] While the present invention has been described with reference to particular embodiments, it will be understood that the embodiments are illustrative and that the invention scope is not so limited. Alternative embodiments of the present invention will become apparent to those having ordinary skill in the art to which the present invention pertains. Such alternate embodiments are considered to be encompassed within the spirit

and scope of the present invention. Accordingly, the scope of the present invention is described by the appended claims and is supported by the foregoing description.

CLAIMS

What is claimed is:

1. A connector for connecting a source board to a target board comprising:
a plurality of transmission channels disposed inside an electrically conductive slab having first and second terminations on respectively first and second surfaces of said slab for transmitting electrical signals or powers between the corresponding input-output terminals of said source board and target board; each of said channels further comprising an electrically conductive member disposed along the central longitudinal axis of a cylindrical cavity with the space between the walls of said cavity and electrically conductive member filled with a low-loss dielectric sleeve; and said cavity having first and second openings coinciding with said first and second terminations of said transmission channel.
2. The connector of claim 1 wherein said electrically conductive slab being entirely made from or having its surfaces coated by material of high electrical conductivity at the highest signal frequency.
3. The connector of claim 1 wherein said dielectric sleeve comprising two or more layers of concentric dielectric materials wrapped or coated around said electrically conductive member.
4. The connector of claim 1 wherein the corresponding channel characteristic impedance being approximated by the characteristic impedance expression of a coaxial transmission line with the cross sectional diameter of said electrically conductive member taken as the diameter of the coaxial inner conductor and said cross sectional diameter of said cylindrical cavity taken as the diameter of the coaxial outer conductor.
5. The connector of claim 3 wherein the corresponding channel characteristic impedance being approximated by the characteristic impedance expression of a coaxial

transmission line with multiple concentric dielectrics separating its inner and outer conductor; and in said approximation, the cross sectional diameters of said electrically conductive member and cylindrical cavity being taken as the diameters of the coaxial inner and outer conductors respectively, the relative dielectric constants of said dielectric sleeve layers being taken as the relative dielectric constants of the corresponding coaxial dielectric materials.

6. The connector of claim 1 wherein said electrically conductive members being double-ended pogo pins each with two end plungers or said pogo pins can be single-ended.

7. The connector of claim 1 wherein said electrically conductive members being receptacles in a female solder type connector, for receiving the respective matching male coupling pins of a male solder type connector having an enclosure which can be slid over to wrap around said slab.

8. The connector of claim 7 wherein the non-mating ends of said receptacles and male coupling pins being extended out of said slab and enclosure respectively, for electrically coupling to the corresponding soldering pads on said source and target boards by soldering or any other suitable means.

9. A method for implementing controlled impedance transmission channels capable of providing shielding against unwanted mutual coupling in connectors, comprising the steps of:

providing a plurality of transmission channels inside an electrically conductive slab having first and second terminations on respectively a first and second surfaces of said slab for transmitting electrical signals and powers between the corresponding input-output terminals of said source board and target board; and further providing an electrically conductive member in each of said channels, said electrically conductive member being disposed along the central longitudinal axis of a cylindrical cavity with the space between the walls of said cavity and electrically conductive member filled with a low-loss dielectric sleeve; and said cavity having first and second openings coinciding with said first and second terminations of said transmission channel; and

each of said electrically conductive member may be coated in a pre-fabrication process with a low-loss concentric dielectric sleeve having predetermined dielectric constant and dimensions to achieve a required channel characteristic impedance value when said coated electrically conductive member is inserted into a channel of said conductive slab.

10. The method of claim 9 wherein said electrically conductive slab being entirely made from or having its surfaces coated by material of high electrical conductivity at the highest signal frequency.

11. The method of claim 9 wherein said dielectric sleeve comprising two or more layers of concentric dielectric materials wrapped or coated around said electrically conductive member.

12. The method of claim 9 wherein the corresponding channel characteristic impedance being approximated by the characteristic impedance expression of a coaxial transmission line with the cross sectional diameter of said electrically conductive member taken as the diameter of the coaxial inner conductor and said cross sectional diameter of said cylindrical cavity taken as the diameter of the coaxial outer conductor.

13. The method of claim 11 wherein the corresponding channel characteristic impedance being approximated by the characteristic impedance expression of a coaxial transmission line with multiple concentric dielectrics separating its inner and outer conductor; and in said approximation, the cross sectional diameters of said electrically conductive member and cylindrical cavity being taken as the diameters of the coaxial inner and outer conductors respectively, the relative dielectric constants of said dielectric sleeve layers being taken as the relative dielectric constants of the corresponding coaxial dielectric materials.

14. The method of claim 9 wherein said electrically conductive members being double-ended pogo pins each with two end plungers or said pogo pins can be single-ended.

15. The method of claim 9 wherein said electrically conductive members being receptacles in a female solder type connector, for receiving the respective matching male coupling pins of a male solder type connector having an enclosure which can be slid over to wrap around said slab.

16. The method of claim 15 wherein the non-mating ends of said receptacles and male coupling pins being extended out of said slab and enclosure respectively, for electrically coupling to the corresponding soldering pads on said source and target boards by soldering or any other suitable means.