

[72] Inventor **John R. Skobern**
Endicott, N.Y.
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[73] Assignee **International Business Machines Corporation**
Armonk, N.Y.

3,460,072 8/1969 Ziegler 333/33
Primary Examiner—Herman Karl Saalbach
Assistant Examiner—T. Vezeau
Attorneys—Hanifin and Jancin and Charles S. Neave

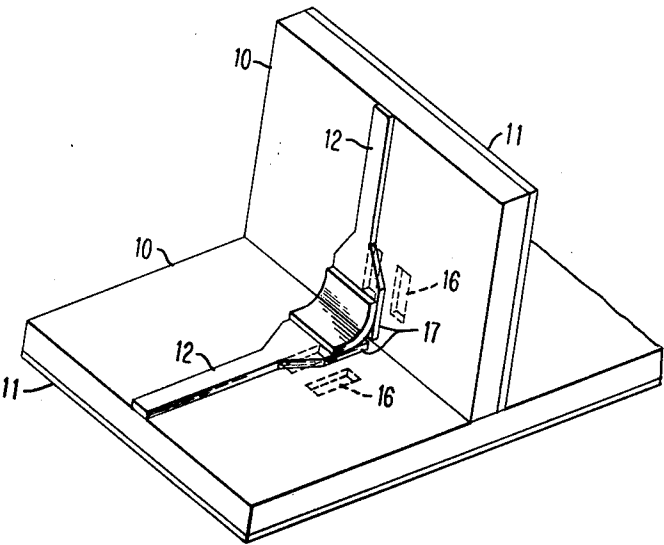
[54] **HIGH-SPEED IMPEDANCE-COMPENSATED CIRCUITS**
11 Claims, 8 Drawing Figs.

[52] U.S. Cl..... 333/33,
333/84
[51] Int. Cl..... H03h 7/38,
H01p 3/08
[50] Field of Search..... 333/32, 33,
84 (M)

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ABSTRACT: Impedance-compensated circuits for high frequency microstrip signal transmission systems comprising a dielectric board of suitable thickness depending upon the dielectric constant of the material of the board and the frequency of the signals to be transmitted within the system. A ground conductor plate is attached to one planar surface of the dielectric board. The other planar surface of the dielectric board is adapted to receive and have affixed thereto any of a plurality of combinations of signal-conducting elements. The signal-conducting elements have predetermined cross-sectional areas depending upon the signals to be transmitted within the system. Due to microminiature construction, the signal-conducting elements may be provided with lead and circuit-connecting areas of increased size to facilitate making electrical connections for devices to be attached with the elements. The impedance changes due to the increased size of areas are compensated for by means of slots or apertures in the ground conductor plate opposite or in the vicinity of the connecting areas.



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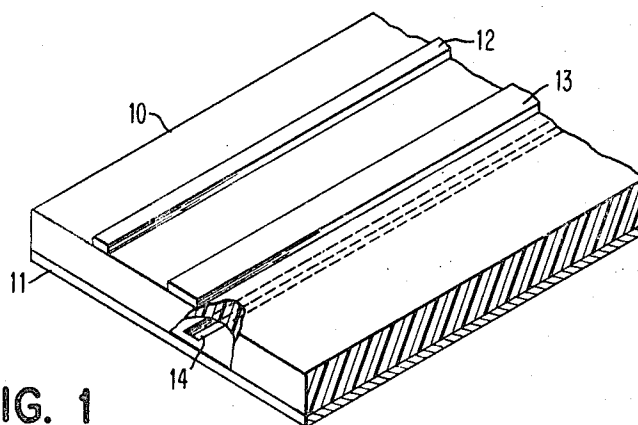


FIG. 1

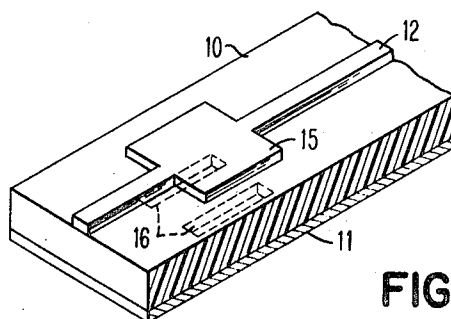


FIG. 2

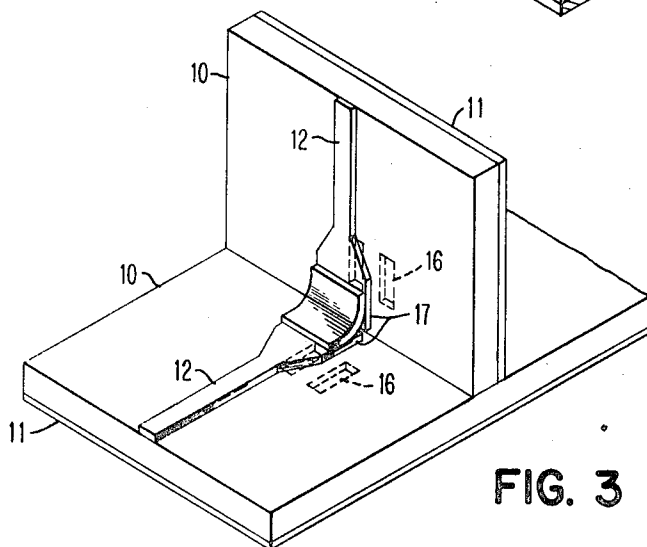


FIG. 3

INVENTOR.
JOHN R. SKOBERN

BY *Charles A. Nease*
AGENT

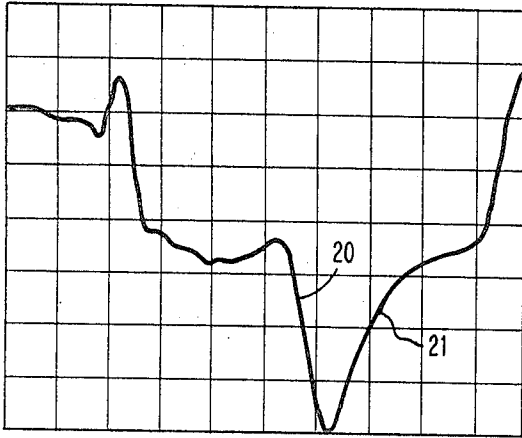


FIG. 4

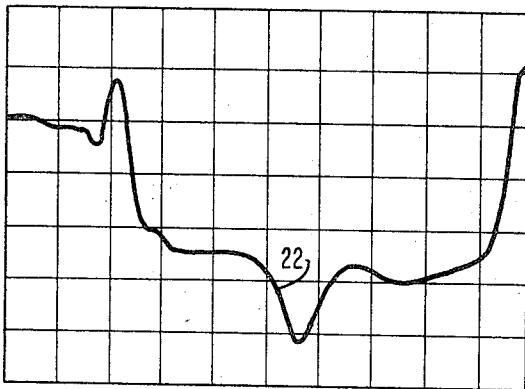


FIG. 5

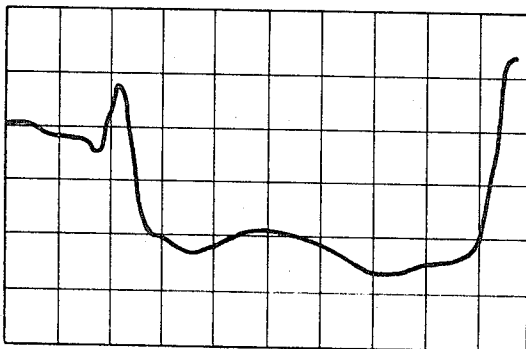


FIG. 6

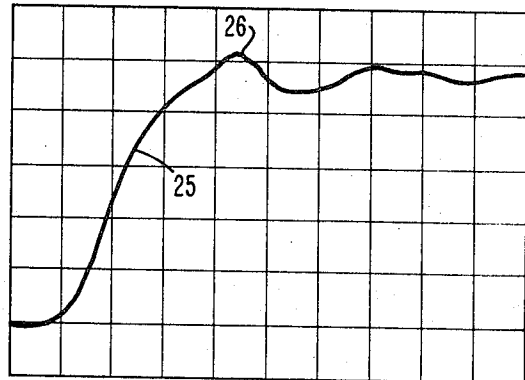


FIG. 7

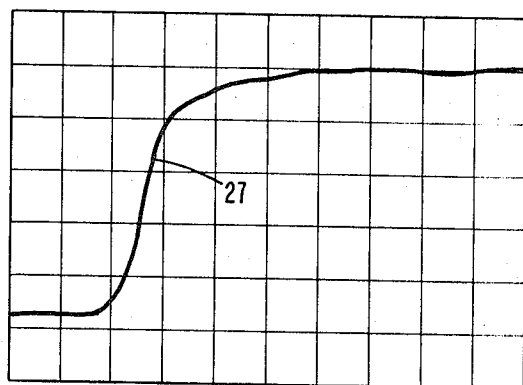


FIG. 8

HIGH-SPEED IMPEDANCE-COMPENSATED CIRCUITS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the signal-transmitting circuits for a high-speed signal transmission system, and more specifically to impedance-compensating arrangements therefor.

2. Description of the Prior Art

In the prior art there are various forms of transmission lines such as coaxial, waveguide, strip, and strip transmission lines in stacked arrays, all particularly adapted to accommodate the transmission of high frequency signals. Transmission lines frequently involve fabrication by printed circuit-wiring techniques. For example, a transmission line may comprise a pair of flat conductors spaced in substantially parallel relation by a flat dielectric board having substantially parallel surfaces. The so-called ground conductor is deposited by any of the recognized printed wiring techniques on one surface of the dielectric board, while the signal conductor of considerably narrower width is deposited by similar techniques on the opposite surface of the dielectric board. Depending on the particular thickness of the dielectric board chosen to hold the signal and ground conductors in spaced relation, a suitable frequency band of electromagnetic wave energy can be propagated along the transmission line. It is recognized that where flat conductors are employed, the electric field cannot be entirely confined within the bounds defined by the signal and ground conductors. Such construction of the conductors tends to occasion some transmission losses due to radiation. The mismatching of line impedances increases the transmission line losses and causes undesirable signal reflections.

The present day trend in data-processing systems is to microminiaturization which involves higher density packaging, a higher speed of operation which necessitates the use of higher signal transmission frequencies with attendant requirements for lower radiation losses, and fewer signal discontinuities. The present day trend introduces problems such as maintaining uniform characteristic impedance when making the component lead connections, corner and interboard coupling connections. Discontinuities and radiation losses in the signals are created at the connecting areas of the signal line conductors.

It is a principal object of the present invention to provide a facile technique for producing a compensated high frequency transmission line.

It is another object to provide a plurality of compensated high frequency transmission lines on the same dielectric board.

It is a further object to provide a high frequency transmission line having substantially uniform impedance characteristics regardless of the various connections made to the transmission line.

SUMMARY OF THE INVENTION

In accordance with the invention there is provided a high frequency transmission line medium with transmission lines such as are used in association with high frequency electronic devices and provided with impedance-compensating means wherever electrical connections are made to the lines in order to maintain a substantially uniform characteristic impedance throughout the entire line. The signal transmission system comprises a solid dielectric having planar insulating layers or board which has one or more elongated signal-conducting strips affixed to one surface and a wide ground plane conductor covering all or substantially all of the other side of the dielectric board, commonly called microstrip transmission line. The signal-conducting strips have predetermined cross-sectional areas dependent upon the signals to be transmitted over the transmission lines. The signal-conducting strips may have one or more intermediate electrical lead-connecting areas of increased size to facilitate the connecting of component leads to the signal-conducting strips. Further, the signal-conducting strips may have coupling pads of increased

size at the board edge to effect interboard electrical connecting. The gist of the invention resides in the use of apertures and/or elongated slots having predetermined dimensional configurations and placed in the ground conductor plane in the vicinity underlying the electrical coupling area or interboard coupling pad. The apertures or slots function to increase the characteristic impedance of the transmission line and offset the decrease in characteristic impedance caused by the increased dimensional areas which are used to accommodate electrical coupling devices.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an amplified isometric view of a circuit board in accordance with the present invention, showing a high-speed transmission line and a compensated line to accommodate the transmission of greater current signals.

FIG. 2 is an amplified isometric view of a transmission line on a printed circuit board showing a lead coupling area and the impedance-compensating means therefor.

FIG. 3 is an amplified isometric view of a transmission line on a printed circuit board provided with edge-connecting pads and impedance-compensating means therefor.

FIG. 4 is a waveform illustration of a test signal propagated down a transmission line and a reflected wave showing the impedance affect caused by a coupling area in the line without compensation.

FIGS. 5 and 6 are waveform illustrations of a test signal propagated down a transmission line and a reflected wave showing the affect of impedance-compensating apertures in the vicinity of the electrical coupling area.

FIG. 7 is a waveform illustration of a signal transmitted over a signal transmission line and illustrating the affect of a coupling pad located at the edge of the dielectric board and without compensation.

FIG. 8 is a waveform illustration showing the improved condition in the reflected wave from the edge-coupling pad of the transmission line when provided with compensation means.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

There is shown in FIG. 1 printed circuit transmission lines in accordance with the invention and comprising a solid dielectric planar insulating board 10 to which is affixed, preferably by printed circuit techniques, a flat layer of conductive material forming a ground conductor plane 11. The flat signal-conducting strips or elements 12 and 13, having predetermined cross-sectional areas dependent upon the signals to be transmitted over the strips and formed of conductive material, are affixed to the opposite surface of the dielectric board 10.

The dielectric board 10 may be composed of any suitable laminating material such as polystyrene, phenolic resin, ceramic, or glass-fiber reinforced epoxy resins. The thickness of the dielectric board 10 is dependent upon the dielectric constant of the material used and the frequency of the signals to be transmitted over the transmission lines.

In FIG. 1, the signal conductor strip 12 and ground conductor plane 11 together function as a signal transmission line having a uniform characteristic impedance, which in the preferred embodiment is 50 ohms. This is due to the parameters of the transmission line, such as thickness of the dielectric board 10, the cross-sectional area of the signal conductor strips 12, and frequency of the signals to be transmitted over the transmission line. It should be noted that other impedances are possible utilizing a different set of parameters which is within artisan capability.

The conductor strip 13 and ground conductor plane 11 together function as a transmission line particularly adapted for transmission of a signal having increased current-carrying capability and/or a decreased resistance requirement. The

ground plane 11 has an elongated slot or aperture 14 of predetermined area dimensions and underlying the signal conductor strip 13. The slot enables the transmission line to maintain the same characteristic impedance as the transmission line comprising strip 12 and ground plane 11.

In FIG. 2, there is shown a high-speed transmission line comprising a dielectric board 10, a ground conductor plane 11, and a signal conductor strip 12. Additionally, signal conductor strip 12 includes a lead-connecting area 15 of increased size to facilitate the process of making electrical connections of component leads and the like to the signal conductor strip 12. The electrical affect of the increased connecting area 15 is to decrease the impedance of the transmission line.

In order to optimize power transfer at the point of connection, the characteristic impedance of the section of the transmission line should match the impedance of the other section of the transmission line. To provide these impedance matches, the characteristic impedance of the transmission line is maintained through the medium of impedance-compensated apertures located in the ground conductor plane.

By experimentation and/or calculation by computer programming, the dimensions of the aperture or slot 16 can be determined and then placed in the ground conductor plane 11 underlying the connecting area 15. This will have an impedance-compensating affect and in this manner a transmission line can be designed and manufactured having a substantial uniform characteristic impedance throughout its length regardless of the number of lead-connecting areas 15 existent in the signal conductor strips 12. It is possible that a signal transmission line on a dielectric board or substrate 10 may have a plurality of lead-connecting areas and each of these areas would have a compensating aperture or slot in the vicinity immediately below the lead-connecting area 15.

Another undesirable affect stems from the capacitive coupling of a component device, such as a transistor or the like, to the transmission line. Because of this coupling condition, there is a discontinuity in the characteristic impedance of the transmission line and which provides undesirable reflections on the transmission line. Such capacitive coupling affect may be substantially overcome by means of a properly oriented compensating aperture.

In FIG. 3, there is shown a high-speed transmission line comprising a dielectric board 10, a ground conductor plane 11, and a signal conductor strip 12. Additionally, the signal conductor strip 12 includes edge or interboard coupling pads 17 of increased size to facilitate the process of making interboard electrical connections to the signal strips 12. Again, the electrical affect of the increased connecting areas is to decrease the impedance of the transmission line. This change in impedance can be offset through the medium of an aperture or slot 16 being placed in the ground conductor plane 11 and underlying the coupling pad areas. The aperture or slot may be a single-hole item or a combination of holes, but the compensating affect in either case will be substantially the same.

For testing purposes a strip transmission line similar to the one shown in FIG. 2 was constructed. A Time Domain Reflectometer, such as is available from Hewlett Packard, was used to observe the electrical performance characteristics and enable comparisons when signals were applied to the line.

As an example, it has been determined empirically and with the use of a Time Domain Reflectometer that for a microstrip transmission line comprising an epoxy glass dielectric 10 ($E_r = 4.4$ generally) of about 0.018 inches thick and a ground-conducting plane 11 of about 0.0017 inches thick, a signal strip 12 of about 0.0017 inches thick and 0.030 inches wide, the characteristic impedance Z_0 is about 50 ohms. When a connecting area 15 of about 0.130 inches long and 0.160 inches wide was introduced into the signal strip, it was necessary to introduce an aperture in the ground conductor plane 11 and underlying the connecting area 15 having a length of 0.150 inches and width of 0.190 inches in order to maintain the characteristic impedance Z_0 of the microstrip transmission line at about 50 ohms.

Tests were conducted on: (1) a normal transmission line with a coupling area with and without compensation apertures in the ground plane; and (2) a normal transmission line with an edge-coupling pad with and without compensation apertures in the ground plane. The characteristics observed were: (1) impedance; (2) slope degradation; (3) velocity of propagation using a trombone time delay device; and (4) reflections on the transmission line.

To illustrate the affects of impedance compensation, references may be made to FIGS. 4 through 8.

Referring to FIG. 4, there is shown a waveform which depicts the affect of a single lead-connecting area in a single line strip when a signal pulse is applied to the line and in which the ground plane is devoid of a compensating aperture. A large capacitive discontinuity may be noted at point 20, which represents the location of the lead-connecting area 15. Also the degradation of the rise time 21 may be noted.

Referring to FIG. 5, there is shown a waveform which depicts the affect of a signal pulse applied to the line but the compensating aperture 16 in the ground plane 11 is of insufficient size to fully compensate the impedance characteristics caused by the increased size of the connecting area 15. A reduction in the capacitive discontinuity 22, as compared with point 20 in FIG. 4, may be noted.

Referring to FIG. 6, there is shown a waveform which illustrates the affect of a well-compensated signal transmission line including the properly designed impedance-compensating aperture 16. In this test the discontinuity is negligible.

Referring to FIG. 7, there is shown a waveform indicating a reflected pulse condition at the dielectric board end of a signal transmission line provided with a coupling pad but without impedance compensation. The degradation of the rise time 25 and the discontinuity 26 may be noted.

In FIG. 8, there is shown a waveform indicating the pulse condition at the dielectric board end of a signal transmission line having the coupling pads but with impedance compensation apertures 16 of proper dimension and placement. By comparing the waveforms of FIGS. 7 and 8, in FIG. 8 the pulse as shown has an improved rise time 27 and the undesirable reflections on the line have been removed.

The characteristics obtained by the signal conductors, connectors, insulating board, and impedance-compensating apertures as used in this invention should be considered illustrative only and not restrictive of either frequency range or dimensional changes as these may be changed by altering the dimensions of the boards, transmission lines, as well as those of the connector areas and impedance-compensating apertures. It should be evident from the foregoing description that this invention is of a very simple construction while maintaining a rather close transmission line configuration with substantially uniform impedance characteristics throughout the length of the transmission line. It will also be evident that the parts are held rigidly together while resulting in a very reliable construction both mechanically and electrically.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

I claim:

1. A high-speed impedance-compensated circuits combination, comprising:

- a dielectric board having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the board;
- a signal line conductor of predetermined cross-sectional area affixed to one surface of the board;
- a ground conductor plane affixed to the opposite side of the dielectric board; said signal line conductor and the ground conductor plane constituting a transmission line having a predetermined characteristic impedance; and
- d. an impedance-compensating aperture in the ground conductor plane opposite to and parallel with the signal line

conductor, the area of the aperture being predetermined so as to establish and maintain a substantially uniform characteristic impedance and to accommodate the transmission of signals of greater current capacity.

2. A high-speed impedance-compensated circuits combination as defined in claim 1 wherein the signal line and ground conductor planes are of the printed circuit type.

3. Impedance compensation for a high-speed circuits arrangement comprising, in combination:

- a. a dielectric board having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the board;
- b. at least one signal line conductor element of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor element and affixed to one surface of the dielectric board;
- c. a ground conductor plane affixed to the opposite side of the dielectric board, each of the signal line conductors electrically in combination with the ground conductor plane adapted to functionally operate as a transmission line possessing uniform impedance characteristics;
- d. the signal line conductors being provided with at least one electrical lead-coupling area of increased portions to facilitate lead connections to the signal line; and
- e. an impedance-compensating aperture in the ground conductor plane opposite each lead-coupling area, the area of the aperture being predetermined so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedance would be decreased due to the increased size of the lead-coupling area.

4. Impedance compensation for high-speed circuits arrangement as defined in claim 3 wherein the signal line and ground conductor planes are of the printed circuit type.

5. Impedance compensation for a high-speed circuits arrangement comprising, in combination:

- a. a substrate having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the substrate;
- b. at least one signal line conductor element of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor element and affixed to one surface of the substrate;
- c. a ground conductor plane affixed to the opposite side of the substrate, each of the signal line conductors electrically in combination with the ground conductor plane adapted to functionally operate as a transmission line possessing uniform impedance characteristics;
- d. the signal line conductors being provided with at least one electrical lead-coupling area of increased portions to facilitate lead connections to the signal line; and
- e. an impedance-compensating aperture in the ground conductor plane opposite each lead-coupling area, the area of the aperture being predetermined so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedance would be decreased due to the increased size of the lead-coupling area.

6. Impedance compensation for a high-speed circuits packaging arrangement comprising, in combination:

- a. a dielectric board having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the board;
- b. at least one signal line conductor element of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor elements and affixed to one surface of the dielectric board;
- c. a ground conductor plane affixed to the opposite side of the dielectric board, each of the signal line conductor elements electrically in combination with the ground conductor plane adapted to functionally operate as a transmission line possessing uniform impedance characteristics;

d. the signal line conductors being provided with corner-coupling pads of increased size terminating the signal lines at the edge of the dielectric board and to facilitate electrical connections with other boards; and

e. an impedance-compensating aperture in the ground conductor plane opposite each of the corner-coupling pads, the area of the aperture being predetermined so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedance would be decreased by the increased size of the corner-coupling pads.

7. Impedance compensation for a high-speed circuits packaging arrangement as defined in claim 6 wherein the signal lines and ground conductor plane are of the printed circuit type.

8. Impedance compensation for a high-speed circuits packaging arrangement comprising, in combination:

- a. a substrate board having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the substrate;
- b. at least one signal line conductor element of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor elements and affixed to one surface of the substrate;
- c. a ground conductor plane affixed to the opposite side of the substrate, each of the signal line conductor elements electrically in combination with the ground conductor plane adapted to functionally operate as a transmission line possessing uniform impedance characteristics;
- d. the signal line conductors being provided with corner-coupling pads of increased size terminating the signal lines at the edge of the substrate and to facilitate electrical connection with other boards; and
- e. an impedance-compensating aperture in the ground conductor plane opposite each of the corner-coupling pads, the area of the aperture being predetermined so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedance would be decreased by the increased size of the corner-coupling pads.

9. Impedance compensation for a high-speed circuits packaging arrangement comprising, in combination:

- a. a dielectric board having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the board;
- b. at least one signal line conductor of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor and affixed to one surface of the dielectric board;
- c. a ground conductor plane affixed to the opposite side of the dielectric board, each of the signal line conductor elements electrically in combination with the ground conductor planes adapted to functionally operate as a transmission line possessing uniform impedance characteristics;
- d. the signal line conductor elements being provided with at least one electrical lead-coupling area of increased portions to facilitate lead connections to the signal line;
- e. the signal line conductor elements being provided with corner-coupling pads of increased area terminating the signal lines at the edge of the circuit board to facilitate electrical connections with other boards; and
- f. impedance-compensating apertures in the ground conductor plane opposite each of the lead-coupling areas and the corner-coupling pads, said apertures being of predetermined sizes so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedances would be decreased by the increased size of the lead-coupling area and the corner-coupling pads.

10. Impedance compensation for a high-speed circuits packaging arrangement as defined in claim 9 wherein the signal lines and ground conductor plane are of the printed circuit type.

11. Impedance compensation for a high-speed circuits packaging arrangement comprising, in combination:

- a. a substrate having parallel surfaces and a predetermined thickness depending upon the dielectric constant of the material of the substrate;
- b. at least one signal line conductor of predetermined cross-sectional area depending upon the signals to be transmitted over said signal line conductor and affixed to one surface of the substrate;
- c. a ground conductor plane affixed to the opposite side of the substrate, each of the signal line conductor elements electrically in combination with the ground conductor planes adapted to functionally operate as a transmission line possessing uniform impedance characteristics;
- d. the signal line conductor elements being provided with at

- least one electrical lead-coupling area of increased proportions to facilitate lead connections to the signal line;
- e. the signal line conductor elements being provided with corner-coupling pads of increased area terminating the signal lines at the edge of the circuit board to facilitate electrical connections with other boards; and
 - f. impedance-compensating apertures in the ground conductor plane opposite each of the lead-coupling areas and the corner coupling pads, said apertures being of predetermined sizes so as to increase the characteristic impedance of the transmission line by substantially the same amount as the impedances would be decreased by the increased size of the lead-coupling area and the corner-coupling pads.

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