(54) Title: SUSPENSION WITH INTEGRATED CONDUCTORS HAVING TRIMMED IMPEDANCE

Ahead suspension has an integrated trace conductor array (16) for supporting and electrically interconnecting a read/write head (26) to electronic circuitry (54) in a disk drive (30). The electrical micro strip transmission line characteristics of the conductor array (16) is controlled by the selective placement and width sizing of shaped openings in the suspension at regions adjacent to the conductor paths.
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SUSPENSION WITH INTEGRATED CONDUCTORS
HAVING TRIMMED IMPEDANCE

Reference to Related Application

This is a continuation-in-part of U.S. Patent Application Serial No. 08/621,431, filed on March 25, 1996, the disclosure thereof being incorporated herein by reference.

Field of the Invention

This invention relates generally to structure and method for controlling electrical impedance characteristics of a trace conductor array formed integrally with a flexure of a head suspension assembly. More particularly, the present invention relates to an integrated suspension and conductor structure wherein the suspension includes voids placed and shaped in order to trim and control impedance parameters and reduce signal reflections.

Background of the Invention

Contemporary disk drives typically include a rotating rigid storage disk and a head positioner for positioning a data transducer at different radial locations relative to the axis of rotation of the disk, thereby defining numerous concentric data storage tracks on each recording surface of the disk. The head positioner is typically referred to as an actuator. Although numerous actuator structures are known in the art, in-line rotary voice coil actuators are now most frequently employed due to their simplicity, high performance, and their ability to be mass balanced about their axis of rotation, the latter being important for making the actuator less sensitive to perturbations. A closed-loop servo system within the disk drive is conventionally employed to operate the voice coil actuator and thereby position the heads with respect to the disk surface.

The read/write transducer, which may be of a single or dual element design, is typically deposited upon a ceramic slider structure having an air bearing surface for supporting the transducer at a small distance away from the surface of the moving medium. Single write/read element designs typically require two wire connections while dual designs having separate reader and writer elements require four wire connections. Magnetoresistive (MR) heads in particular generally require four wires. The combination of an air bearing slider and a read/write transducer is also known as a read/write head or a recording head.
Sliders are generally mounted to a gimbaled flexure structure attached to the distal end of a suspension's load beam structure. A spring biases the load beam and the head towards the disk, while the air pressure beneath the head pushes the head away from the disk. An equilibrium distance defines an "air bearing" and determines the "flying height" of the head. By utilizing such an "air bearing" to support the head away from the disk surface, the head operates in a hydrodynamically lubricated regime at the head/disk interface rather than in a boundary lubricated regime. The air bearing maintains spacing between the transducer and the medium which reduces transducer efficiency. However, the avoidance of direct contact vastly improves the reliability and useful life of the head and disk components. Demand for increased areal densities may nonetheless require that heads be operated in pseudo contact or even boundary lubricated contact regimes, however.

Currently, flying heights are on the order of 0.5 to 2 microinches. The magnetic storage density increases as the head approaches the storage surface of the disk. Thus, a very low flying height is traded against device reliability over a reasonable service life of the disk drive. At the same time, data transfer rates to and from the storage surface are increasing; and, data rates approaching 200 megabits per second are within practical contemplation.

The disk drive industry has been progressively decreasing the size and mass of the slider structures in order to reduce the moving mass of the actuator assembly, to permit closer operation of the transducer to the disk surface, and to reduce the overhead otherwise taken up by a "landing zone" for contact start-stop recording. Lower moving mass gives rise to improved seek performance while closer slider-disk spacing gives rise to improved transducer efficiency that can then be traded for higher areal data storage density. The size (and therefore mass) of a slider is usually characterized with reference to a so-called standard 100% slider ("minislider"). The terms 70%, 50%, and 30% slider ("microslider", "nanoslider", and "picoslider", respectively) therefore refer to more recent low mass sliders that have linear dimensions that are scaled by the applicable percentage relative to the linear dimensions of a standard minislider. Smaller slider structures generally require more compliant gimbals, hence the intrinsic stiffness of the conductor wires attached to the slider can give rise to a significant undesired bias effect.

To reduce the effects of this intrinsic wire stiffness or bias, integrated flexure/conductor structures have been proposed which effectively integrate the wires with an insulating flexible polymeric resinous flexure such that the conductors are exposed at bonding pads positioned at the distal end of the flexure in the proximity of the
head. U.S. Patent No. 5,006,946 to Matsuzaki discloses an example of such a configuration. U.S. Patent No. 5,491,597 to Bennin et al. discloses a further example in point. While such wiring configurations do enjoy certain performance and assembly advantages, the introduction of the disclosed flexible polymeric resinous material in the flexure and gimbal structure raises a number of challenging design issues. For example, the thermal expansion properties of the resinous material is not the same as the prior art stainless steel structures; and, the long-term durability of such resinous structures, including any requisite adhesive layers, is unknown. Therefore, hybrid stainless steel flexure and conductor structures have been proposed which incorporate most of the benefits of the integrated conductor flex-circuit flexure structures while remaining largely compatible with prior art fabrication and load beam attachment methods. Such hybrid designs typically employ stainless steel flexures having deposited insulating and conductive trace layers for electrical interconnection of the head to the associated drive electronics, e.g., a proximately located preamplifier chip and downstream read channel circuitry typically carried on a circuit board (along with other circuitry) attached to the head/disk assembly.

As taught by U.S. patent No. 5,491,597 to Bennin et al., entitled: "Gimbal Flexure and Electrical Interconnect Assembly", the disclosed prior approach called for use of a spring material for the conductive trace layers, such as beryllium-copper alloy, which admittedly has higher electrical resistance than pure annealed copper, for example. On the other hand, pure annealed copper, while a satisfactory electrical conductor at high frequencies manifests high ductility rather than spring-like mechanical resilience, and therefore lacks the desirable mechanical spring properties desired in the interconnect trace material. Traces formed of pure copper plated or deposited onto e.g. a nickel base layer provide one alternative to the beryllium-copper alloy relied upon by the Bennin et al. approach.

These hybrid flexure designs employ relatively lengthy runs of conductors which extend from bonding pads at the distal, head-mounting end of the flexure to the proximal end of the flexure, to provide a conductive path from the read/write head along the length of the associated suspension structure to the preamplifier or read-channel chip(s). Because the conductors are positioned extremely close to, but electrically isolated from, the conductive stainless steel flexure structure which is in turn grounded to the load beam, and because of the relatively high signal rates being transferred, the conductor inductance and mutual coupling, as well as conductor capacitance to ground can give rise to unwanted signal reflections and inefficient signal/power transfer. The unwanted signal
reflections tend to deleteriously affect the performance of the read/write head, interconnect structure, and driver/preamplifier circuit.

Micro strip line technology teaches that the loop and inter-conductor capacitance may be changed by changing the dimensions of and/or spacing between micro strips forming a transmission line. However, in the case of integrated wiring schemes for use with head suspension load beams, the dimensions of the conductors are governed by mechanical constraints including the space available on the flexure for the interconnect structure, and the trace conductor dimensions cannot be changed very much insofar as impedance matching or tuning is concerned.

The invention to be described provides, inter alia, a flexure for a suspension in a disk drive which includes integrated conductor structure having a controllably tuned impedance configured to reduce signal reflections by controlling conductor and ground plane opening geometry.

Summary of the Invention with Objects

A general object of the present invention is to provide a low-profile, robust and reliable high performance suspension assembly having integral conductors for electrically interconnecting a read/write head to associated read/write circuitry which overcomes limitations and drawbacks of the prior art.

Another general object of the present invention is to provide an integrated suspension and conductor structure having controlled geometries relative to a ground plane such that reflections are reduced and optimized power transfer is achieved, in a manner overcoming limitations and drawbacks of the prior art.

A more specific object of the present invention is to provide a method for controlling capacitance, mutual inductance and overall impedance of an integrated flexure/conductor structure for use with a read/write head in a disk drive.

Still another object of the present invention is to provide an integrated flexure and conductor structure and fabrication method that facilitates the separate optimization of the capacitance and impedance of the conductors of both the read and the write elements of a dual-element read/write head.

Another object of the present invention is to provide an improved suspension for supporting read/write heads in the drive.
A suspension assembly in accordance with principles of the present invention includes a flexure having one or more shaped voids and having integrated conductors which extend along the flexure controllably adjacent to the voids. The integral conductors replace prior art discrete twisted-pair, insulated conductor wires which would normally extend along the length of the associated suspension. The size and shape of the flexure voids as well as the conductor geometry and placement relative to the flexure voids are used to reduce undesirable effects of conductor capacitance to ground and to optimize transmission line impedance to terminal device impedance. The invention provides improved electrical performance without materially affecting the suspension’s mechanical performance.

The invention provides an economical and reliable method for electrically connecting a transducer mounted on a slider to an integrated flexure/conductor structure which implements a gimbal and includes exposed conductive electrical bonding pads positioned near the slider mounting region at the distal end of a conductive flexure. The bonding pads and associated conductors are electrically isolated from the flexure by a dielectric layer affixed to the flexure with the conductors extending generally coplanarly along a flexure surface. The flexure includes one or more voids and the conductors are configured to extend adjacent to the voids. The conductor aspect ratio and the interconductor spacing may be tailored to reduce the mutual capacitance between conductors while concurrently maintaining low capacitance to ground. The boundaries of the voids may be configured to prevent discontinuous impedance changes along the conductor path.

These and other objects, advantages, aspects, and features of the present invention will be more fully appreciated and understood upon consideration of the following detailed description of preferred embodiments presented in conjunction with the accompanying drawings.

**Brief Description of the Drawings**

In the Drawings:

Fig. 1 is an enlarged, diagrammatic plan view of a disk drive including a suspension assembly having a tuned conductive trace array incorporating principles of the present invention.
Fig. 2 is an enlarged diagrammatic plan view of a first preferred embodiment of integrated flexure/conductor load beam structure having tuned conductive traces in accordance with principles of the present invention.

Fig. 3 is an enlarged plan view of a flexure of the Fig. 2 load beam structure having integral wiring incorporating the tuned conductive trace array.

Fig. 3A is a greatly enlarged plan view of a read/write head connection region of the Fig. 3 flexure trace array and wherein the head slider is shown in dashed line outline.

Fig. 3B is a greatly enlarged view in elevation and cross-section taken along section line 3B-3B in Fig. 3.

Fig. 3C is a greatly enlarged view in perspective of a slider end of the Fig. 2 load beam structure showing the slider attached to the flexure gimbal, and showing electrical gold ball connections between the flexure trace array and the read/write head connection pads of the slider.

Fig. 4 is a greatly enlarged view in elevation and cross-section of an alternative embodiment of the present invention.

Fig. 5A is a plan view showing an alternative embodiment of a read/write head and load beam including integral trace connector flexure structure in accordance with principles of the present invention.

Fig. 5B is a greatly enlarged plan view of the Fig. 5A alternative load beam structure showing the flexure as having integral two conductor wiring for a single element read/write head and incorporating controlled voids in accordance with principles of the present invention.

Fig. 5C is an enlarged view in section and elevation taken along section line 5C-5C in Fig. 5B.

Fig. 5D is a greatly enlarged portion of the Fig. 5A sectional view.

Figs. 6A, 6B, 6C, 6D and 6E illustrate a variety of exemplary window outlines which may be defined in an integrated flexure/conductor structure in accordance with principles of the present invention.
Fig. 7 is a simplified electrical circuit model of the Fig. 3C dual-element read/write head and interconnect structure, and driver/preamplifier circuit chip of the disk drive shown in Fig. 1.

Fig. 8 is a distributed-parameters network for a two-conductor interconnect structure for the Fig. 7 model.

Fig. 9 is a more generalized electrical circuit schematic showing a distributed-parameters network for the read element of the Fig. 7 model.

Fig. 10 is a more generalized electrical circuit schematic showing a distributed-parameters network for the write element of the Fig. 7 model.

Figs. 11A, 11B and 11C are a series of graphs illustrating electrical resistance, inductance and capacitance, respectively, of the Fig. 3B trace interconnect structure as a function of ground plane window width.

Fig. 12 is a graph of characteristic electrical impedance of the Fig. 3B trace interconnect structure as a function of ground plane window width defined by the flexure.

**Detailed Description of Preferred Embodiments**

Referring to the drawings, where like characters designate like or corresponding parts throughout the views, Fig. 1 presents a diagrammatic top plan view of a head/disk assembly (HDA) of a hard disk drive 30. The hard disk drive 30 employs at least one load beam assembly 10 having a flexure 14 including a trace interconnect array 16 as a first preferred embodiment of the present invention. Fig. 1 shows the load beam assembly 10 with the flexure 14 and trace interconnect array 16 employed within its intended operating environment.

In the present example disk drive 30 includes e.g. a rigid base 32 supporting a spindle 34 (and spindle motor, not shown) for rotating at least one storage disk 36 in a direction shown by the curved arrow. Drive 30 also includes a rotary actuator assembly 40 rotationally mounted to the base 32 at a pivot point 35. The actuator assembly 40 includes a voice coil 42 which, when selectively energized by control circuitry (not shown), moves and thereby positions an actuator E-block 44 and head arms 46 (and load beam assemblies 10) at radial track positions defined on the facing surfaces of storage
disks 36. At least one of the load beam assemblies 10 is secured at its proximal end 17 to a distal end of a head arm 46, e.g. by conventional ball-swaging techniques.

Conventionally, but not necessarily, two load beam assemblies 10 are attached to head arms 46 between disks 36; and, one load beam structure 10 is attached to head arms above and below the uppermost and lowermost disks of a disk stack comprised of multiple disks 36 spaced apart on spindle 34. The interconnect structure 16 connects to a flexible trace/film segment 50 which extends to a hybrid circuit substrate 52 secured to a side of the E-block 44. The hybrid circuit 52 secures and connects a semiconductor chip 54 forming a read preamplifier/write driver circuit. Most preferably, the chip 54 is nested between the substrate of the hybrid circuit 52 and the E-block sidewall, and is secured to the sidewall by a suitable conductive adhesive or thermal transfer compound such that heat generated during operation of the chip 54 is dissipated into the E-block by conduction, and outwardly into the ambient air volume by convection.

As shown in Figs. 2, 3, 3A, 3B and 3C, the load beam assembly 10 includes a generally planar formed stainless steel load beam 12 and a flexure 14. In the present example, the flexure 14 is formed of thin stainless steel sheet material which is e.g. approximately 20-microns thick. An array of two pairs of conductive traces 60 and 62 of approximately 10-microns thick copper conductor forms part of an interconnect structure 16 which extends from the proximal end 17 of flexure 14 to another connection pad array 22 located at the slider-supporting distal end 18 of the load beam assembly 10. A transducer head slider 20 is attached to the gimbal 14 by a suitable adhesive at the distal end 18 of the load beam structure 10. As shown in Fig. 3C the connection pads 22 at the distal end 18 are provided for connection by e.g. ultrasonically-welded gold ball bonds 56 to aligned connection pads 24 of a dual-element (four conductor) thin film magneto-resistive read/write structure 26 formed on a trailing edge of the slider body 20. Preferably, although not necessarily, the slider body 20 is a 30% slider.

Interconnect structure 16 includes a high dielectric polyimide film base 25 interposed between the conductive traces 60 and 62 of the conductor array 16 mounted to the stainless steel flexure 14. The dielectric layer is preferably about 10-microns thick. In accordance with principles of the present invention, the flexure 14, in addition to providing a gimbal mounting for the read/write head, defines one or more openings or troughs 28 of controlled width (w) and placement relative to the conductive traces 60 and 62 of the conductor structure 16 These longitudinal openings 28 defined along flexure 14 are arranged and spaced relative to the conductor array 16 in a manner enabling e.g. inductance, capacitance and resistance components of line impedance of the conductor
structure to be tuned by varying the width dimension (w) relative to the array 16 as discussed hereinafter in connection with Figs. 7A, 7B and 7C. Accordingly, the present invention provides a method for tuning and controlling the electrical properties of impedance, including inductance, capacitance and resistance components, of the conductor array 16 arising from integration thereof with the stainless steel flexure 14.

At high data signal frequencies the interconnect structure 16 behaves as a microstrip transmission line for carrying the signals passing between the read/write head and read/write preamplifier/driver chip 54. Accordingly, the geometry of the openings or recesses 28 is also an important factor for controlling impedance along the signal path of trace conductor structure 16, as discussed hereinafter in connection with Figs. 6A-6D.

As shown in Fig. 3B, interconnect array 16 includes, in this embodiment, at least one pair of conductive traces 60 and 62, and an insulating polyimide (a flexible polymeric resinous material) layer 64 which spans the longitudinal window or void 28 defined in the thin stainless steel flexure 14. Although not strictly required, an additional insulation layer of about 4-microns thickness may be provided to protect the traces 60 and 62. As the spacing between the conductive traces 60 and 62 is varied, the loop inductance and the inter-conductor capacitance changes. By controlling the width dimension (w) of the window or void 28, a desired impedance value (inductance and capacitance) for a given conductor configuration may be obtained. By controllably reducing or removing the electrical ground plane formed by flexure material from below the conductors 60 and 62, capacitance to ground is reduced, and inductance is increased. Since inductance is a critical parameter that must be minimized in a current sensing scheme typically employed with MR read elements, the present approach calls for removing only so much of the ground plane material of flexure 14 in the proximity of the conductor traces 60 and 62 as is necessary to reach desired electrical parameters as well as maintaining structural flexing properties needed for proper performance of the flexure 14 in supporting the slider 20 while flying in close proximity to the facing surface of a disk 36 during disk drive operations.

Fig. 4 is a greatly enlarge diagrammatic view of a modification of the Fig. 3B structure, illustrating a division of the two signal traces 60 and 62 into two segments apiece, namely trace segments 60A and 60B for the trace 60, and trace segments 62A and 62B for the trace segment 62. The modification of Fig. 4 may be employed in trace interconnects wherein it is desirable to reduce the inductance of the interconnect traces without noticeably increasing the capacitance.
Fig. 5A is a plan view of an alternative embodiment 10' of integrated flexure/conductor structure following principles of the present invention. Flexure/conductor structure 10' includes a generally planar stainless steel flexure member 14 which is approximately 20-microns thick and which includes tooling holes 13 and 15 which are used during manufacturing and assembly for precision component alignment. In the embodiment of Fig. 5A, a single pair of conductive traces 60 and 62 of approximately 10-microns thick copper form part of the conductor array 16' which extends from the proximal end 17 of load beam assembly 10' to the head supporting distal end 18 of load beam assembly 10'. Conductor array structure 16' includes a thin (e.g., 10-microns thickness) insulating base film 25 interposed between the conductive traces 60 and 62 of the conductor structure 16' and stainless steel flexure member 14' to prevent electrical shorting of the conductive traces of conductor structure 16'. As shown in Figs. 5A and 5B, flexure member 14' defines one or more longitudinal voids 28 which are positioned adjacent to the path along which conductor structure 16' is routed in order to control electrical parameters, particularly capacitance, between the conductor structure 16' and the stainless steel flexure 14'.

Discontinuous impedance changes tend to give rise to undesirable reflection effects in the transmission line properties of conductor array 16. Fig. 5C illustrates a cross section of the flexure/conductor structure 10' of Fig. 5B taken along section line 5C-5C. Conductor trace array structure 16' includes, in this embodiment, a pair of conductive traces 60 and 62 and an insulating polyimide (a flexible polymeric resinous material) layer 25 which spans the void 28 to provide support and alignment for the conductive traces 60 and 62. Although not strictly required, an additional insulation layer 27 (shown in Fig. 3B) of about 4-microns thickness may be provided as a protective overcoat for the traces 60 and 62.

Preferably, the windows or voids 28 should be shaped so as to cause a smooth or relatively continuous change in the cross-sectional area of the window 28 along the length of flexure 14 so as to avoid abrupt transitions in the impedance along the signal path defined by conductor structure 16. In the areas where the boundaries of the windows 28 cross the traces 60 and 62, it is desirable to either curve the boundary or angle the boundary so that the boundary does not cross the traces at a right angle, so that the impedance changes along the micro strip transmission line defined by conductive trace array structure 16 are made more gradual. Additionally, the flexure member interior boundary that defines windows 28 may be undercut (as shown in Figs. 5C and 5D) to further smooth impedance changes along the signal path.
Figs. 6A, 6B, 6C, 6D and 6E illustrate several alternative window shapes that may be employed adjacent to either the read or write signal path to control the capacitance of that signal path. Fig. 6A illustrates a substantially rectangular interior boundary defining a void in a flexure member. Although the illustrated void helps to reduce the magnitude of the capacitance to ground, the perpendicular crossing of the conductor and the void boundary can give rise to a sharp or step-function transition in the impedance along the conductor path.

For a single conductor, the capacitance per unit length is approximated by:

\[
\frac{C_s}{l} = 8.84\varepsilon_0 K_c \left(\frac{b}{l}\right) \text{ pF/m}
\]

where:

- \( C_s \) = capacitance to ground
- \( l \) = length of conductor
- \( \varepsilon_0 \) = dielectric constant
- \( K_c \) = capacitive fringing factor
- \( b \) = conductor width
- \( t \) = thickness of insulator

The capacitance to ground of the conductor regions near the boundary but adjacent the conductive flexure member is therefore substantially different from the capacitance to ground of the conductor regions near the boundary but adjacent the void. This abrupt capacitance change gives rise to an approximately step-function impedance change in the conductor as it crosses the boundary.

In high frequency applications, step function changes in impedance along the conductor path cause traveling wave reflections that distort the transmitted waveform. Therefore, curved or angled void boundaries such as those disclosed in Figs. 6B-6D appear to provide better high frequency performance than the void boundary illustrated in Fig. 6A. Of course, the thickness of the flexure member 14, which acts as the ground plane, may also be varied (Fig. 5A) to cause a more gradual impedance change for any of the void geometries illustrated in Figs. 6A-6D. It should be noted that the void boundary may be either an interior or exterior boundary of the flexure member 14, since windows or voids 28 may be formed along a lateral edge of the flexure member, for example.

Fig. 6E illustrates an interconnect trace array wherein the flexure member 14* is perforated to define a series of openings 28 at the vicinity of the conductor trace array
structure. While openings are shown, the flexure may be patterned to define dimples or recesses in lieu of openings in a pattern such as the pattern shown in Fig. 6E by die stamping or coining techniques, for example.

Numerous methods for laminating and patterning stainless steel sheet stock, dielectric films, and conductors are known in the art. Additionally, methods for depositing and patterning dielectric and conductors onto stainless steel are also known in the art. In accordance with a preferred embodiment of the invention, the conductive traces 60 and 62 are plated and photolithographically defined, rather than laminated and etched, so that the insulation and conductive trace layers may be made suitably thin so as not to materially affect the mechanical properties of the stainless steel flexure member. After the insulator and conductor structures are formed, the outlines of the flexure 14 and the windows 28 may be selectively etched to complete the formation of an integrated flexure 14-conductor trace array structure 16.

Fig. 5 shows the fully assembled head gimbal assembly (HGA) 10' in accordance with principles of the invention as including a base plate 32 for mounting the HGA 10' to an actuator arm 46 in the disk drive 30 and a load beam 12' for applying a load force onto read/write head slider 20. Slider 20 is affixed to the distal end 18 of load beam assembly 10' and the transducer element of read/write head 26 are electrically interconnected to the conductive traces 60 and 62. Flexure 14 may be conventionally spot welded to load beam 12' at locations 13, for example. Load beams 12 and 12' typically include a protuberance or load button (not shown) which approximates point contact between load beam and the slider 20 so that the slider 20 is capable of limited relative pitch and roll with respect to load beam 12, 12' and disk 36 during head flying operation. It should be noted that although the load beam 12, 12' is a conductive stainless steel structure (like flexures 14, 14') in the preferred embodiments of the invention, the conductive traces 60 and 62 are positioned sufficiently far from the load beam itself so as not to give rise to significant electrical parameter issues, such as capacitance to ground. If, however, a load beam structure having an integrated gimbal is employed so that the intermediate flexure 14 described in connection with Figs. 4 and 5 is not required, in accordance with the principles of the invention, the load beam itself may be etched or formed so as to define longitudinal windows or voids along the signal path in order to control electrical impedance characteristics and reduce capacitance to ground.

Fig. 7 presents a highly simplified electrical model of the head 26, interconnect trace array structure 16 and chip 54. The read conductors 60R and 62R conduct a
substantially constant small direct current to a thin film sensor 70 having magneto-resistive (MR) properties. The read sensor 70 may alternatively have so-called "giant magneto-resistive" (GMR) or "colossal magneto-resistive" (CMR) properties. A flux transition field proximate to the MR sensor 70 causes a change in resistance in the sensor 70. The change in resistance in the presence of a constant current results in a change in voltage which is sensed by a read preamplifier circuit within the chip 54. The actual properties of the sensor 70 will determine the magnitude of voltage amplitude change in response to the magnetic flux change. Since the analog signal being sensed by the sensor 70 is at a very high frequency, the integrated trace conductors 60R and 62R function as a micro strip transmission line.

Fig. 8 presents an electrical schematic model of two-conductor micro strip transmission network. Parameters are obtained on a per-meter-length basis, and are cascaded to model a physical circuit. At low frequencies the parameters may be combined and the network simplified to obtain a lumped-parameter circuit. As shown in Fig. 8, the network includes a series resistance \( R_s'(f) \) obtained in ohms per meter, a series inductance \( L_s(f) \) in henrys per meter, an inter-conductor capacitance \( C_c' \), and a capacitance to ground for each conductor \( C_g' \), both capacitance being measured in farads per meter. In theory the basic network is repeated a number of times to describe the distributed nature of these circuit parameters. In practice the number of cascaded networks is determined by convergence criteria, and a number is chosen to limit the error within predetermined bounds of accuracy.

As described, the conductors 60 and 62 within the interconnect trace array structure 16 are formed as printed circuit traces. For frequencies of interest from e.g. 1 MHz to 1 Ghz, a distributed-parameters network of resistance, inductance and capacitance for the interconnect 16 may be approximated by a lumped-parameters model as shown in Fig. 8. This model shows the series resistance \( R_s(f) \), the series inductance \( L_s(f) \), the inter-conductor capacitance \( C_g' \), and the capacitance to ground \( C_g' \) of each conductor. The inductance and resistance take into account the skin and proximity effect phenomena, and are therefore functions of frequency. They also account for the induced eddy currents in the ground plane 66 when present. The capacitance is independent of signal frequency. All parameters are functions of the geometry of the interconnect 16. Coupling between conductors 60R and 62R of the read channel, and between conductors 60W and 62W of the write channel, is minimized because of physical separation of major trace segment regions as shown in Figs. 2 and 3, and further because of the fact that writing and reading are mutually exclusive at any instant of operation of the disk drive 30 shown in Fig. 1.
Thus, in one example, Fig. 9 sets forth a lumped-parameters model of the MR read element 70, the read paths of the interconnect 16, and the chip 54; and, Fig. 10 sets forth a lumped-parameters model of the thin film inductive write element 72, the write paths of the interconnect 16 and the chip 54. These read and write models enable the designer in practicing the present invention to adjust the ground plane window 68 in order to tune the interconnect impedance to the terminal impedance, given a predetermined trace geometry.

The variation in resistance, short-circuit inductance and open-circuit capacitance parameters, graphed respectively in Figs. 11A, 11B and 11C as a function of ground plane window width W in microns, applies to a conductor geometry as shown in Fig. 3B, wherein conductor strips 60 and 62 are approximately 10 by 100 microns in cross-section and lie in a plane with a separation of approximately 30 microns, and wherein the 10 micron polyimide dielectric layer 25 is imposed between the strips 60 and 62 and the stainless steel flexure 14 forming the electrical ground plane 66. Fig. 12 graphs the change of the real component of characteristic impedance (a complex quantity) of a two-trace micro strip interconnect 16, such as shown in Figs. 4 and 5, as a function of window width W.

The window W may be precisely defined in the flexure 14 by any suitable forming method, including etching, grinding, stamping, coining. Also, the window W may be formed in sections as a trough which combines to strengthen a beam portion of the flexure 14 and as a controlled opening which aids flexibility of spring sections of the flexure 14 (or load beam 12). Also, the ground plane 66 may be formed as a metal layer separate from the load beam, should that be desired, and should desired mechanical properties for the load beam structure thereby be realized.

Those skilled in the art will recognize that, in accordance with the principles of the invention, advanced dual element transducer designs (such as an MR head 26 of Fig. 3C) may have the capacitance and/or impedance of the signal paths of the read and write elements separately optimized by employing different conductor geometries and/or the void configurations for the read and write conductive trace array segments, respectively.

Although the present invention has been described in terms of the presently preferred embodiment, i.e., a deposited conductor flexure structure which implements a gimbal, it should be clear to those skilled in the art that the present invention may also be utilized in conjunction with, for example, an integrated gimbal load beam structure, or other conductive suspension members having proximately mounted, deposited, or embedded conductors with or without insulating overcoatings. Thus, it should be
understood that the instant disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the true spirit and scope of the invention.
What is claimed is:

1. An integrated flexure/conductor structure for supporting a read/write head adjacent to a storage medium and for electrically interconnecting the head to read/write circuitry, the flexure/conductor structure comprising:
   a generally planar conductive flexure member defining at least one generally longitudinal window;
   an electrical insulation layer disposed on the flexure member and at least partially overlaying the generally longitudinal window; and,
   a plurality of electrically conductive traces disposed on the electrical insulation layer and extending along and at least partially overlaying the window.

2. The integrated flexure/conductor structure of claim 1 wherein the conductive traces pass over a non-perpendicular edge of the window so that impedance changes along the conductive traces near a boundary of the window are substantially continuous.

3. The integrated flexure/conductor structure of claim 2 wherein a cross sectional area of the void defined by upper and lower surfaces of the flexure member and a boundary of the window changes substantially continuously along the length of the flexure member.

4. An integrated flexure/conductor structure for supporting a read/write head adjacent to a storage medium and for electrically interconnecting the head to read/write circuitry, the flexure/conductor structure comprising:
   a generally planar conductive flexure member having a boundary defining a void;
   electrically conductive traces disposed adjacent to the flexure member and at least partially overlaying the void; and
   an electrical insulation layer interposed between the flexure member and the traces for electrically isolating the flexure member from the traces.

5. The integrated flexure/conductor structure of claim 4 wherein the conductive traces comprise distinct read and write traces for conducting signals to and from the head.

6. The integrated flexure/conductor structure of claim 4 wherein the conductive traces comprise a plurality of traces forming a single signal path, thereby to reduce the inductance of the single signal path.
7. The integrated flexure/conductor structure of claim 4 wherein the boundary is an interior boundary.

8. The integrated flexure/conductor structure of claim 4 wherein the boundary is an exterior boundary.

9. The integrated flexure/conductor structure of claim 4 wherein the boundary is one of an exterior and an interior boundary, and wherein impedance changes along the conductive traces near the boundary are substantially continuous.

10. The integrated flexure/conductor structure of claim 4 wherein a cross sectional area of the void defined by upper and lower surfaces of the flexure member and the boundary changes substantially continuously along the length of the flexure member.

11. The integrated flexure/conductor structure of claim 4 wherein the flexure member has a thickness which tapers towards the boundary.

12. The integrated flexure/conductor structure of claim 4 wherein the interior boundary is undercut.

13. The integrated flexure/conductor structure of claim 4 wherein an orthogonal projection of the electrically conductive traces onto the planar conductive flexure member intersects the void.

14. The flexure/conductor structure of claim 13 wherein the flexure member is stainless steel.

15. The flexure/conductor structure of claim 14 wherein the electrically conductive traces comprise a metal component selected from the group consisting of aluminum, copper, gold, and silver.

16. The flexure/conductor structure of claim 15 wherein the insulation layer is a flexible polymeric resinous material.

17. A laminated conductor and suspension structure for supporting a read/write head adjacent to a storage medium, the structure comprising:
a generally planar conductive load beam having a proximal actuator mounting end and a gimbaled head mounting region at a distal end for attaching the head, the load beam including a boundary defining a void;

electrically conductive traces disposed adjacent to the load beam and partially overlying the void, wherein impedance changes along the conductive traces near the boundary are substantially continuous; and

an electrical insulation layer interposed between the load beam and the traces for electrically isolating the load beam from the traces.

18. An integrated-conductor suspension for supporting a read/write head adjacent to a storage medium and for electrically interconnecting the head to read/write circuitry, the suspension comprising:

   a base plate at a proximal actuator mounting end of the suspension;

   a load beam connected to the base plate;

   a generally planar conductive flexure member attached to the load beam and having a boundary defining a void;

   electrically conductive traces disposed adjacent to the flexure member and at least partially overlaying the void, wherein impedance changes along the conductive traces near the boundary are substantially continuous; and

   an electrical insulation layer interposed between the flexure member and the traces for electrically isolating the flexure member from the traces.

19. An integrated-conductor head gimbal assembly for reading information from and writing information to a storage medium in a disk drive, the head gimbal assembly comprising:

   a base plate at a proximal mounting end of the head gimbal assembly;

   a load beam connected to the base plate;

   a generally planar conductive flexure member attached to the load beam and having a boundary defining a void;

   electrically conductive traces disposed adjacent to the flexure member and at least partially overlaying the void, wherein impedance changes along the conductive traces near the boundary are substantially continuous;

   an electrical insulation layer interposed between the flexure member and the traces for electrically isolating the flexure member from the traces; and

   a read/write head affixed to the flexure member at a distal end of the head gimbal assembly and electrically connected to the conductive traces.
20. A disk drive for storing and reproducing information, the disk drive comprising:
   a disk drive base;
   a storage disk rotatably mounted to the base;
   motor means for rotating the disk;
   a read/write head for reading information from and writing information to the storage disk;
   signal processing means for communicating with the read/write head;
   a movable actuator mounted to the base for selectively positioning the head relative to a radius of the storage disk; and
   an integrated-conductor suspension attached to the actuator for supporting the head adjacent to the storage disk and for electrically interconnecting the head to the signal processing means, the suspension comprising:
   a base plate at a proximal actuator mounting end of the suspension;
   a load beam connected to the base plate;
   a generally planar conductive flexure member attached to the load beam and having a boundary defining a void;
   electrically conductive traces disposed adjacent to the flexure member and at least partially overlaying the void, wherein impedance changes along the conductive traces near the boundary are substantially continuous;
   an electrical insulation layer interposed between the flexure member and the traces for electrically isolating the flexure member from the traces; and
   wherein the head is mechanically affixed to the conductive flexure member at a distal end of the suspension and is electrically connected to the conductive traces and there through to the signal processing means.

21. The disk drive of claim 20 wherein the head includes separate read and write elements and the conductive traces comprise distinct read and write traces for conducting signals to and from the read and write elements, respectively.

22. The disk drive of claim 21 wherein the boundary is optimized with respect to the read traces.

23. The disk drive of claim 21 wherein the boundary is optimized with respect to the write traces.
24. An integrated load beam/conductor structure for supporting a read/write head adjacent to a rotating data storage disk and for electrically interconnecting the head to read/write circuitry, the load beam/conductor structure comprising:

a generally planar sheet metal load beam member having an interconnect region characterized by a structural feature;

an electrical insulation layer disposed on the interconnect region and overlying the structural feature; and

a stripline pair of electrically conductive traces disposed on the electrical insulation layer, the structural feature underlying at least portions of the stripline pair of conductive traces, the structural feature being defined in order to control electrical impedance of the stripline.

25. The integrated load beam/conductor structure set forth in claim 24 wherein the structural feature has a predetermined transverse width dimension, and the electrical impedance of the stripline is controlled by controlling the predetermined transverse width dimension.

26. The integrated load beam/conductor structure set forth in claim 24 wherein the structural feature is a window defined by adjacent portions of the interconnect region of the load beam member.

27. The integrated load beam/conductor structure set forth in claim 24 wherein the window is defined to have a predetermined shape and the stripline passes over an angled edge of the window such that that impedance changes along the conductive traces near a boundary of the window are substantially continuous.

28. The integrated load beam/conductor structure set forth in claim 24 wherein the structural feature comprises a pattern formed in the interconnect region.

29. The integrated load beam/conductor structure set forth in claim 28 wherein the pattern comprises a series of holes formed in the interconnect region.

30. The integrated load beam/conductor structure set forth in claim 28 wherein the pattern comprises a series of recesses defined in the interconnect region.

31. The integrated load beam/conductor structure set forth in claim 24 wherein the structural feature comprises a trough defined in the interconnect region of the load beam member.
32. A conductor and suspension composite structure for supporting a read/write head adjacent to a storage medium, the structure comprising:
   a generally planar conductive load beam structure having a proximal actuator mounting end and a gimbaled head mounting region at a distal end for attaching the head, the load beam structure defining a structural feature along an interconnect region thereof, the structural feature having a defined width;
   an electrical insulation layer attached to the load beam structure along the interconnect region,
   at least one pair of electrically conductive traces forming a micro strip line disposed on the electrical insulation layer adjacent to the load beam structure and partially overlying the structural feature such that by varying the width of the structural feature the electrical impedance of the micro strip line may be trimmed.

33. The composite structure set forth in claim 32 wherein the structural feature comprises an opening defined by adjacent portions of the interconnect region of the load beam structure.

34. The composite structure set forth in claim 32 wherein the structural feature comprises a longitudinal trough following at least a section of the micro strip line defined by the load beam structure.

35. The composite structure set forth in claim 32 wherein the generally planar conductive load beam structure further comprises a flexure including the gimbaled head mounting region and wherein the structural feature comprises at least one generally longitudinal window defined by the flexure along the interconnect region and wherein the window transverse width dimension is varied in order to trim the electrical impedance of the micro strip line.

36. An integrated-conductor suspension for supporting a read/write head adjacent to a storage medium and for electrically interconnecting the head to read/write circuitry, the suspension comprising:
   a base plate at a proximal actuator mounting end of the suspension;
   a generally planar conductive load beam attached to the base plate at the proximal actuator mounting end,
   a flexure secured to the load beam and including a gimbaled head mounting region at a distal end for attaching the head, the flexure defining a structural feature along an interconnect region thereof, the structural feature having a controlled width;
an electrical insulation layer attached to the load beam along the interconnect
region,
at least one pair of electrically conductive traces forming a micro strip line
disposed on the electrical insulation layer adjacent to the load beam and partially
overlying the structural feature such that by varying the width of the structural feature the
electrical impedance of the micro strip line may be trimmed.

37. The integrated-conductor suspension set forth in claim 36 wherein the
read/write head comprises a magneto resistive read element and an inductive write
element, wherein there are two pairs of electrically conductive traces, one pair for
interconnecting the magneto resistive read element and the other pair for interconnecting
the inductive write element, wherein the flexure extends substantially longitudinally along
the load beam, wherein the pairs of electrically conductive traces include separated
longitudinal segments separately defined along longitudinal edge regions of the flexure,
and wherein there are a plurality of structural features, a first feature underlying the one
pair along one longitudinal edge region, and a second feature underlying the second pair
along a second longitudinal edge region.

38. A disk drive for storing and reproducing information, the disk drive
comprising:
a disk drive base;
a storage disk rotatably mounted to the base and rotated by disk motor means;
a slider for flying in
a dual-element magneto resistive read/inductive write head for reading information
from and writing information to the storage disk;
a movable actuator mounted to the base for selectively positioning the head
relative to a radius of the storage disk;
electrical active element circuit means mounted to a side of the moveable actuator
for communicating with head;

and

an integrated-conductor suspension attached to the actuator for supporting the
head adjacent to the storage disk and for electrically interconnecting the head to the signal
processing means, the suspension comprising:
a generally planar conductive load beam structure having a proximal
actuator mounting end and a gimbaled head mounting region at a distal end for attaching
the head, the load beam structure including a structural feature along an interconnect
region thereof, the structural feature having a defined width;
an electrical insulation layer attached to the load beam structure along the interconnect region, and
at least one pair of electrically conductive traces forming a micro strip transmission line disposed on the electrical insulation layer adjacent to the load beam and partially overlying the structural feature such that by varying the width of the structural feature the electrical impedance of the micro strip line may be trimmed.

39. The disk drive of claim 38 wherein the head includes separate read and write elements and the conductive traces comprise read and write trace pairs for conducting signals to and from the read and write elements, respectively.

40. The disk drive of claim 39 wherein the load beam structure comprises two pairs of electrically conductive traces, one pair for interconnecting the read element and the other pair for interconnecting the write element, wherein the load beam structure includes a flexure secured to a load beam and extending substantially longitudinally along the load beam, wherein the pairs of electrically conductive traces include separated longitudinal segments separately defined along longitudinal edge regions of the flexure, and wherein there are a plurality of structural features, a first feature underlying the one pair along one longitudinal edge region, and a second feature underlying the second pair along a second longitudinal edge region

41. The disk drive of claim 38 wherein the structural feature comprises an elongated opening having the defined width.

42. The disk drive of claim 41 wherein the elongated opening has a controlled geometry to minimize signal reflections otherwise occurring along the micro strip transmission line by passage over an edge of the opening.

43. An actuator structure for a hard disk drive including a disk drive base; a storage disk rotatably mounted to the base; motor means for rotating the disk; a read/write head for reading information from and writing information to the storage disk; signal processing means for communicating with the read/write head; the actuator structure being rotatably mounted to the base for selectively positioning the head relative to a radius of the storage disk and including a voice coil operated by voice coil control means within the disk drive; and further comprising: an integrated-conductor suspension attached to the actuator structure for supporting the head adjacent to the storage disk and for facilitating electrical interconnection of the head to the signal processing means, the suspension comprising:
a base plate at a proximal actuator mounting end of the suspension;
a load beam connected to the base plate;
a generally planar conductive flexure member attached to the load beam and
having a boundary defining a void;
electrically conductive traces disposed adjacent to the flexure member and at least
partially overlaying the void,
an electrical insulation layer interposed between the flexure member and the traces
for electrically isolating the flexure member from the traces,
the head being mechanically affixed to the conductive flexure member at a distal
end of the suspension and electrically connected to connection pads of the conductive
traces at the distal end, and
a conductor array interconnecting with connection pads of the electrical
conductive traces at a proximal end of the integrated-conductor suspension and with the
signal processing means.

44. The actuator structure set forth in claim 43 wherein the signal processing
means includes a preamplifier/write driver chip mounted to a side of the actuator structure
such that heat generated in the preamplifier/write driver chip may be dissipated by
conduction to the actuator structure.

45. The actuator structure set forth in claim 43 wherein the electrically conductive
traces comprise a micro strip transmission line and wherein a width dimension of the void
is trimmed relative to the conductive traces in order to control impedance characteristics
of the micro strip transmission line.

46. The actuator structure set forth in claim 45 wherein the void has a controlled
geometry to minimize signal reflections otherwise occurring along the micro strip
transmission line by passage over an edge of the void.
FIG. – 8

FIG. – 9

FIG. – 10

SUBSTITUTE SHEET (RULE 26)
FIG. 11A

FIG. 11B

FIG. 11C

FIG. 12

SUBSTITUTE SHEET (RULE 26)


INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : G11B 5/55, 21/10
US CL : 360/104
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 360/104

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>X</td>
<td>US 5,491,597 A (BENNIN et al) 13 February 1996, see figure 1</td>
<td>1,4-7,13-28, 31-46</td>
</tr>
<tr>
<td>X</td>
<td>US 5,126,904 A (SAKURAI) 30 June 1992, see figure 3c</td>
<td>1-46</td>
</tr>
<tr>
<td>X</td>
<td>US 4,996,623 A (ERPELDING ET AL) 26 February 1991, see figures 6 and 7.</td>
<td>1-46</td>
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</table>

Further documents are listed in the continuation of Box C. See patent family annex.

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Date of mailing of the international search report: 30 JAN 1998

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