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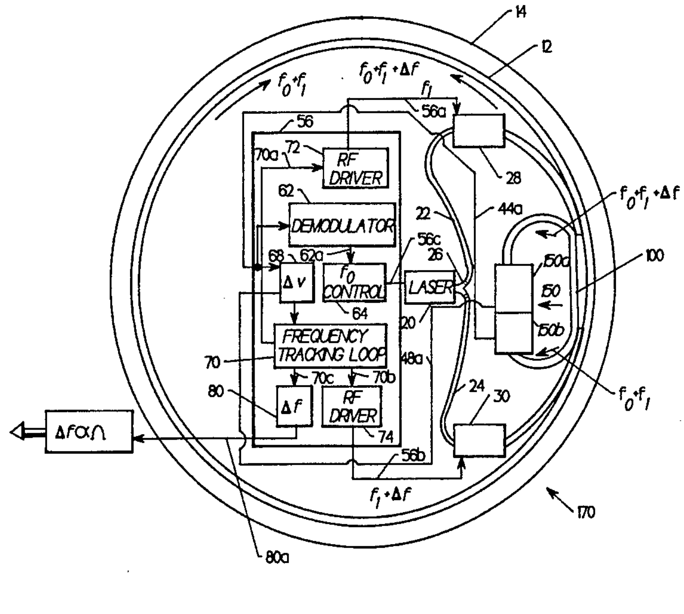

(57) Abstract

A closed loop laser gyroscope utilizes a single directional coupler for coupling coherent optical signals in opposite directions in a circuital thin film waveguide. The directional coupler also receives a portion of each oppositely directed signal for use in a bi-cell detector which outputs signals representative of the intensity of the oppositely directed signals. The utilization of a single directional coupler maximizes gyroscope sensitivity by providing the capability to optimize coupling to increase the resonant cavity's Q-factor, and to reduce the distortion introduced to the laser via resonant optical feedback. Utilization of a bi-cell detector allows detection of both ring-waveguide resonator output signals at only one location on the substrate of the gyroscope, thereby minimizing the effects of temperature gradients across the substrate.

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WAVEGUIDE CONFIGURATION FOR AN INTEGRATED OPTIC GYRO

TECHNICAL FIELD

This invention relates to inertial instruments, and more particularly, to laser gyroscopes.

BACKGROUND ART

Commonly assigned U.S. Patent No. 4,326,803, issued April 27, 1982 describes thin film laser gyroscopes, also known as micro-optic gyroscopes (MOGs). Therein, a Sagnac effect is said to define a linear relationship between the rate of rotation of a circuital waveguide, or loop, and the difference in frequency in oppositely directed electromagnetic wave disturbances travelling through that waveguide at resonance.

In U.S. Patent No. 4,326,803 issued April 27, 1982, entitled "Thin Film Laser Gyro", to Lawrence, there is described a thin film, passive waveguide that provides a substantially closed circular propagation path for optical signals. A laser and associated beam splitter are adapted to generate two coherent optical signals. A first directional coupler introduces the two optical signals to the waveguide in a manner establishing oppositely directed coherent optical signals in the waveguide. In one embodiment, both optical signals are frequency-controlled so that these signals resonate within the waveguide. Frequency control for the optical signals may be achieved by the use of acousto-optic modulators, such as Bragg cells, which shift the frequency of applied optical signals as a function of a frequency of a radio frequency (RF) signal applied to the modulator. With this configuration, the optical signals from a laser and a beam splitter pass along separate paths, through the frequency shifters, directional couplers, and into the waveguide. In addition, optical detectors and a second directional coupler are adapted to detect the intensity of the oppositely-directed optical signals in the waveguide. Servo networks responsive to the detectors generate the RF signals for controlling the frequencies of the optical signals (by way of the modulators) that are injected into the waveguide in their respective directions.

In U.S. Patent No. 4,514,088, issued April 30, 1985, entitled "Single-Coupler Guided-Wave Passive Resonant-Ring Optical-Gyro Instrument" to Coccoli, there is described a single-coupler guided-wave passive resonant-ring optical gyro system that is responsive to a coherent light source and includes an optical-fiber resonant ring, as opposed to a thin film planar waveguide, and a single directional fiber coupler. The directional coupler serves as an input for exciting clockwise and counterclockwise traveling wave resonances in the resonant fiber ring and serves as an output for extracting the output signals representative of those resonant traveling waves.

In U.S. Patent No. 4,456,377 issued June 26, 1984, entitled, "Multimode Fiber Optic Rotation Sensor", to Shaw et al., there is described a fiber optic rotation sensor that utilizes a multimode optical fiber to improve power coupling and reduce back scattering.

In U.S. Patent No. 4,480,915 issued November 6, 1984, entitled "Ring Interferometer Device And Its Application To The Detection Of Non-Reciprocal Effects", to Arditty et al., there is described a ring interferometer device that causes two fractions of a coherent radiation to travel in opposite directions in a closed loop. The device detects the interference of the two radiations after traveling through the loop, and provides a filter for selecting a particular mode among all the modes likely to be propagated in the loop and to arrive at the detection device.

In U.S. Patent No. 4,747,111 issued May 24, 1988, entitled "Quasi-Planar Monolithic Unidirectional Ring Laser", to Trutna, there is described a quasi-planar monolithic unidirectional ring laser that includes an Nd:YAG crystal that is used for the ring. The crystal is geometrically shaped so that the desired ring configuration is imposed by internal reflections. In a crystal in which the front face serves as the output coupling port, a slanted rear face can serve as the locus of the center reflection defining the plane characterized by the out-of-plane angle.

In U.S. Patent No. 4,445,780 issued May 1, 1984, entitled "Fiber Optic Rotation Sensing Gyroscope With (3x2) Coupler", to Burns, there is described a Sagnac gyroscope having an optical coupler with three input waveguides, wherein a middle input waveguide is disposed between two outer input waveguides, and with two output waveguides forming branching ends of a central coupling waveguide structure. The waveguides are disposed in a common plane about an axis of symmetry in the common plane. The middle input waveguide is adapted to transmit a light beam into the coupler and the output waveguides are optically coupled to the ends of a fiber-optic loop. The intensities of the light beams exiting the coupler via the outer input waveguides are measured and compared to determine the rate of rotation.

DISCLOSURE OF THE INVENTION

Accordingly, it is an object of the present invention to provide an improved passive thin film (i.e. integrated optic) ring resonator laser gyroscope that utilizes a single directional coupler.

It is another object of the invention to provide a thin film laser gyroscope that is less complex to manufacture, thereby increasing the device yield and decreasing manufacturing costs.

The laser gyro of the present invention is an improvement upon the laser gyro described in commonly assigned U.S. Patent No. 4,326,803 issued April 27, 1982, entitled "Thin Film Laser Gyro" to Lawrence. As was previously described, the laser gyro described in that patent utilizes two directional couplers. One of the directional couplers introduces the two optical signals to the waveguide in a manner establishing oppositely directed coherent optical signals in the waveguide. The second directional coupler receives a portion of each oppositely directed coherent optical signal in the waveguide in order for the two separate detectors to detect the intensity of each signal.

The laser gyroscope of the present invention utilizes a single directional coupler and a bi-cell detector to perform the same functions as the two directional couplers and the two separate detectors, respectively, in U.S. Patent No. 4,326,803.

The single directional coupler technique of the present invention maximizes the optical signal-to-noise ratio at both coupler outputs, increases the Q-factor of the resonant cavity by reducing the total coupler loss, and reduces distortion introduced to the laser via resonant optical feedback. The reduction in the number of couplers also results in less stringent tolerances in fabricating the directional coupler, thereby reducing manufacturing costs.

The bi-cell detector concept of the present invention allows detection of both oppositely directed coherent optical signals in the waveguide at just one location on the substrate, on which the waveguide is disposed, thereby minimizing temperature gradients across the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention will be made more apparent in the ensuing detailed description of the invention when read in conjunction with the attached drawing, wherein:

FIG. 1 shows the basic configuration of the laser gyroscope of the prior art utilizing two directional couplers and two separate detectors;

FIG. 2 shows an alternate embodiment of the laser gyroscope of FIG. 1;

FIG. 3 shows the basic configuration of the laser gyroscope of the present invention, which is an improvement upon the configuration of FIG. 1, utilizing one directional coupler and one bi-cell detector; and,

FIG. 4 shows an alternate configuration of the laser gyroscope of the present invention which is an improvement upon the configuration of FIG. 2.

MODES OF CARRYING OUT THE INVENTION

Fig. 1 shows the laser gyro 10 of U.S. Patent No. 4,326,803. In the configuration of Fig. 1, gyro 10 includes a thin film, dielectric waveguide 12 defining a circular propagation path for optical signals. The waveguide 12 is disposed on a planar substrate 14. A controllable frequency laser 20 is also disposed on substrate 14. The laser 20 includes two output ports leading to thin film optical waveguides 22 and 24 for transmitting coherent optical signals from the laser. Waveguide 22 is coupled by way of a frequency shifter 28 to a directional coupler 32. Similarly, waveguide 24 is coupled by way of a second frequency shifter 30 to the directional coupler 32. The frequency shifters 28 and 30 may be conventional acousto-optic modulators such as Bragg cells.

The waveguides 22 and 24 and frequency shifters 28 and 30 are configured with respect to coupler 32 and the waveguide 12 so that optical signals travelling from the laser 20 by way of waveguide 22 are coupled to the waveguide 12 in a first direction (clockwise as shown in Fig. 1) and optical signals travelling from the laser 20 by way of waveguide 24 are coupled to the waveguide 12 in the opposite direction (counterclockwise as shown in Fig. 1). A second directional coupler 34 is disposed on the opposite side of the waveguide 12 from coupler 32. Thin film waveguides 38 and 40 extend from coupler 34 to detectors 44 and 48, respectively. The coupler 34, waveguide 38 and detector 48 are configured so that detector 48 receives a portion of counterclockwise travelling optical signal in waveguide 12. Detector 48 in turn is responsive to that received signal to generate a signal on line 48a representative of the intensity of that counterclockwise optical signal in waveguide 12. Similarly, the coupler 34, waveguide 38 and detector 44 are configured so that detector 44 receives a portion of the clockwise-travelling optical signal in waveguide 12. Detector 44 is responsive to that received signal to generate a signal on line 44a representative of the intensity of the clockwise optical signal in waveguide 12.

The use of just one coupler allows the unique possibility (i.e. not possible with multi-coupler resonators) of achieving complete destructive interference on resonance at the output detector. The coupling is set to equal the round trip loss in the resonator. Under these conditions, the intensity contrast (off versus on resonance) is maximized and the signal-to-noise ratio is optimized.

This technique also has the advantage of eliminating resonant feedback from the circuital waveguide onto the laser.

It has been found that the utilization of one directional coupler, as shown in Fig. 3, further maximizes gyroscope sensitivity because the total coupling loss to the ring waveguide resonator 20 can be reduced, thereby increasing the Q-factor of the resonant cavity. A high Q-factor resonator requires weak total coupling, i.e., the more "taps" on the cavity, the weaker each tap or coupling must be. As it is very difficult to fabricate an ultra-weak coupler, the fabrication of only one coupler, at a relatively higher coupling level, is clearly preferred.

The preferred embodiment of the invention utilizes a directional coupler having a double-concave geometry that is formed by two curved waveguides, though of different radius of curvature. In contrast to a coupler formed, for example, via a straight waveguide and a curved waveguide, the double-concave coupler achieves the desired coupling over a relatively long interaction length and as such has proved to be more tolerant of fabrication errors.

It has also been found that utilization of a bi-cell detector, in place of separate detectors, minimizes temperature gradients across the substrate, because detection of both ring waveguide resonator output signals occur at one location on the substrate.

Fig. 3 shows a laser gyroscope 170 and is a presently preferred embodiment of the invention. Elements corresponding to elements in the embodiment of the configuration in Fig. 1 are identified with the same reference designations. Directional coupler 100 and bi-cell detector 150 are utilized in place of couplers 32 and 34, and detectors 44 and 48, respectively, of Fig. 1. Coupler 100 performs the same function as couplers 32 and 34 of Fig. 1. Coupler 100 is optically coupled to waveguide 20 and has two inputs and two outputs. One of the inputs is coupled to the output of frequency shifter 28 while the other input is coupled to the output of frequency shifter 30. Waveguides 22 and 24, and frequency shifters 28 and 30, are configured with respect to coupler 100 and waveguide 12 so that optical signals emanating from laser 20 and travelling through Y-branch beam splitter 26 and waveguide 22 are coupled to waveguide 12 in a first direction (clockwise), as shown in Fig. 3, and optical signals travelling through waveguide 24 are coupled to waveguide 12 in the opposite direction (counterclockwise), as shown in Fig. 3.

Coupler 100 has one output coupled to a first input of bi-cell detector 150 while the other output of coupler 100 is coupled to a second input of bi-cell detector 150. Bi-cell detector 150 has two detector cells 150a and 150b which perform the same functions as detectors 48 and 44, respectively.

Cell 150b of bi-cell detector 150 receives a portion of the first coherent optical signal travelling in the first direction (clockwise) in waveguide 12, while cell 150a of bi-cell detector 150 receives a portion of the second coherent optical signal travelling in the second direction (counterclockwise) in waveguide 12. Cell 150b outputs a signal that represents the intensity of the first coherent optical signal in waveguide 12. Cell 150a outputs a signal that represents the intensity of the second coherent optical signal.

A control network 56 is responsive to the signals from bi-cell detector 150 to provide control signals on lines 56a and 56b for adjusting the frequency shift provided by shifters 28 and 30, respectively. In addition, the control network 56 provides a center frequency control signal on line 56c which adjustably controls the center frequency, f_0, of laser 20.

The control network 56 includes a demodulator 62 and an f_0 control network 64. The demodulator 62 is responsive to the intensity signal on line 44a to provide an output signal on line 62a proportional to the amplitude of the clockwise optical signal in the waveguide 12. The f_0 control network 64 generates the laser f_0 control signal on line 56c, in response to the signal applied from line 62a. This occurs in a closed-loop manner, which maximizes the intensity of the clockwise signal in waveguide 12, thereby causing the optical signal along that path to achieve resonance.

The control network 56 also includes a difference amplifier 68, a frequency tracking loop 70, and a first RF driver 72 and a second RF driver 74. The frequency tracking loop 70 generates a frequency standard control signal which is applied by way of line 70a to RF driver 72, which in turn provides a fixed RF signal at frequency f_1 on line 56a to the frequency shifter 28. With this configuration, the clockwise wave in waveguide 12 is thereby controlled to be f_0+f_1.

In addition, the frequency tracking loop 70 is responsive to the output from the difference amplifier 68 (which detects the difference between the intensities of the counter propagating optical signals in waveguide 12) to provide a servo control signal on line 70b which minimizes this difference. The servo control signal for the tracking loop is applied by way of line 70b to variable frequency RF driver 74, which in turn provides an output RF signal on line 56b to frequency shifter 30 so that the counterclockwise optical signal has a frequency equal to a nominal frequency f_0+f_1, plus or minus an additional component Δf which is necessary to shift the frequency of the counterclockwise optical signal in waveguide 12 to be resonant.

The control network 56 also provides an output signal on line 70c which is applied to a frequency comparator 80. Frequency comparator 80 in turn provides an output signal on line 80a proportional to the difference in frequency between the RF signal control signals applied to the frequency shifters 28 and 30. This signal is proportional to the rotation of the waveguide 12. When the waveguide 12 is at rest in inertial space, Δf equals 0; when waveguide 12 rotates about an axis normal to the plane of the waveguide, Δf is proportional to the rate of turn, in accordance with the Sagnac effect.

In operation, the laser frequency is modulated by the f_0 control 64. The amplitude of the frequency scan is maintained so that it scans across the resonator peak, from one inflection point to its opposite. The f_0 control 64 then examines the demodulated signal from detector 44 and determines whether the laser line and the resonator peak center are coincident. If an error signal is detected, indicating lack of coincidence, f_0 control 64 changes the laser frequency until centering is achieved. The frequency response of this loop extends from DC to a relatively high frequency in order to maintain servo lock in the presence of disturbances, such as mechanical and acoustic vibrations, and frequency jitter in the laser itself.

When the servo loop is locked on the resonator peak for the clockwise path, the difference signal is examined for rate information. The differential output rate signal (ΔV)

provided by network 68 drives a frequency tracking loop 70 that introduces a frequency shift (Δf) between the drive to the acousto-optic shifters operating on the CW and CCW signals. The direction and sign of Δf are adjusted by the frequency tracking loop until the two peaks are brought back to a complete overlap condition. The waveguide, in effect, provides two interferometers which differ in path length but which, because of the differing wavelengths, both contain an integral number of wavelengths. When the ΔV is nulled, Δf relates linearly to rate. The Δf, read out as the rate signal, is the difference frequency between the signals to the acousto-optic frequency shifters for the CW and CCW paths. A center frequency of 300 MHz for the shifters requires that the two oscillators maintain a stable frequency difference of as low as 1 Hz and, for high rate situations, as high as a few hundred KHz.

Fig. 2 shows laser gyroscope 1 which is an alternate embodiment of the laser gyroscope of Fig. 1 where elements corresponding to elements in the embodiment of Fig. 1 are identified with the same reference designations. Fig. 4 shows an alternate embodiment of the present invention which is an improvement over the laser gyroscope configuration in Fig. 2. In Fig. 4, coupler 100 and bi-cell detector 150 replace couplers 32 and 34, and detectors 44 and 48, respectively. The output from laser 20 is split by Y-branch beam splitter 26 and is coupled by way of frequency shifters 28 and 30 and coupler 32 to waveguide 12. Portions of the counter rotating optical signals in waveguide 12 are applied by way of coupler 34 and waveguides 38 and 40 to bi-cell detector 150. Bi-cell detector 150 is comprised of detector cells 150a and 150b. The frequency of laser 20 is controlled by a clock signal and modulator 92. A first feedback network (including detector cell 150a, demodulator 94, and voltage-to-frequency convertor 104) controls the frequency (f_0+f_1) of the counterclockwise signal in waveguide 12 by way of frequency shifter 34b. A second feed back network (including detector cell 150b, demodulator 102, and voltage-to-frequency convertor 96) controls the frequency (f_0+f_2) of the clockwise signal in waveguide 12 by way of frequency shifter 34a. In that f_1 and f_2 are derived from low jitter RF oscillators, the frequency jitter in f_0+f_1 and f_0+f_2 are substantially identical. The rate information may be determined by measuring the difference between the two frequencies f_1 and f_2. The measurement of the waveguide path length difference is accomplished by servoing f_0+f_1 for the counterclockwise optical signal in waveguide 12 to its resonant frequency in the waveguide (by means of the first electronic network which detects the intensity of that optical signal and then servos the frequency of the frequency shifter to maximize that intensity), and similarly, servoing f_0+f_2 for the clockwise optical signal to its resonant frequency. In this way, the difference Δf between f_1 and f_2 is directly proportional to the inertial rotation rate of the waveguide about an axis normal to the plane of the waveguide. When the gyro is at rest in inertial space, $\Delta f = 0$ and both optical paths have the same resonant frequency. A component of the rotation normal to the plane of the waveguide will cause Δf to be non-zero.

In accordance with the invention, one servo loop controls one VCO of the two VCO's, and a second servo loop controls the laser.

Based on the foregoing teaching, those having skill in the art may derive a number of modifications to the embodiments of the invention disclosed above. Thus, the invention is not to be construed to be limited only to these disclosed embodiments, but it is instead intended to be limited only as defined by the appended claims.

What is claimed is:

1. A passive ring resonator laser gyroscope, comprising:

a thin film, planar waveguide providing a closed, passive propagation path for optical signals;

coupling means, utilizing a single directional coupler, for coupling first and second coherent optical signals into the waveguide, the first and second coherent optical signals being oppositely directed in the waveguide and having frequencies F1 and F2, respectively, the single directional coupler also receiving and outputting a portion of the first and the second coherent optical signals traveling in the waveguide; and,

closed loop control means for controlling the frequencies of the first and second coherent optical signals that are coupled into the waveguide by the single directional coupler, the waveguide being resonant at frequency F1 and at frequency F2 for the first and second coherent optical signals, respectively.

2. The laser gyroscope as set forth in claim 1, further comprising means for generating a rate signal representative of a difference in frequency of the first and second coherent optical signals in the waveguide, the rate signal being representative of the angular rate of the waveguide.

3. The laser gyroscope as set forth in claim 1, further comprising:

a laser for generating a coherent optical beam; and,

a beam splitting means for splitting the coherent optical beam into first and second optical beams.

4. The laser gyroscope as set forth in claim 3 wherein the frequency control means includes a first frequency shifter means for shifting the frequency of the first optical beam in

response to a first control signal to provide the first coherent optical signal.

5. The laser gyroscope as set forth in claim 4 wherein the frequency control means includes a second frequency shifter means for shifting the frequency of the second optical beam in response to a second control signal to provide the second coherent optical signal.

6. The laser gyroscope as set forth in claim 3 wherein the frequency control means further includes means, associated with the laser, for controlling the frequency of the coherent optical beam.

7. The laser gyroscope as set forth in claim 1 wherein the single directional coupler has two inputs and two outputs and is optically coupled to the waveguide.

8. The laser gyroscope as set forth in claim 3 wherein the frequency control means further comprises detector means having two inputs and two outputs, the first of the inputs being coupled to the first of the outputs of the single directional coupler, the second of the inputs of the detector means being coupled to the second of the outputs of the single directional coupler, the detector means outputting at the first output a first detection signal representative of the intensity of the first optical signal in the waveguide, the detector means outputting at the second output a second detection signal representative of the intensity of the second optical signal in the waveguide.

9. The laser gyroscope as set forth in claim 8, further comprising:

a first feedback network responsive to the first detection signal to generate the first control signal; and,

a second feedback network responsive to the second detection signal to generate the second control signal.

10. The laser gyroscope as set forth in claim 1 wherein the single directional coupler has a double-concave geometry.

11. A passive ring resonator laser gyroscope comprising:

a thin film, passive waveguide for providing a closed, substantially circular propagation path for optical signals;

means for generating first and second coherent optical signals that are approximately equal in frequency;

means for shifting the frequency of the first coherent optical signal in response to a first control signal;

means for shifting the frequency of the second coherent optical signal in response to a second control signal;

coupling means utilizing a single directional coupler for coupling the first coherent optical signal having the shifted frequency to the waveguide, whereby the first coherent optical signal travels in the waveguide in a first direction, the single directional coupler coupling the second coherent optical signal having the shifted frequency to the waveguide, whereby the second coherent optical signal travels in the waveguide in a direction opposite to the first direction;

detector means coupled to the directional coupler and including a bi-cell detector having two detector cells, the first detector cell generating a first signal representative of the intensity of the first coherent optical signal in the waveguide, the second detector cell generating a second signal representative of the intensity of the second coherent optical signal in the waveguide;

first feedback network means responsive to the first signal to generate the first control signal whereby the intensity of the first coherent optical signal in the waveguide is maximized;

second feedback network means responsive to the second signal to generate the second control signal whereby the intensity of the second coherent signal in the waveguide is maximized; and,

means, coupled to the detector means, for generating a signal representative of the difference in frequencies of the first and second coherent optical signals in the waveguide.

12. A passive ring resonator laser gyroscope, comprising:

a thin film waveguide providing a closed, passive propagation path for optical signals;

laser means, responsive to a control input, for generating a coherent light beam;

first signal generating means for generating a first signal having a first frequency, said first signal generating means having an input and an output;

second signal generating means for generating a second signal having a second frequency, said second frequency generating means having an input and an output;

first frequency shifter means having two inputs and an output, one of the inputs being coupled to the output of the first signal generating means;

second frequency shifter means having two inputs and an output, one of the inputs being coupled to the output of the second signal generating means;

beam splitting means having an input and two outputs, the input being coupled to the output of the laser means, the beam splitting means splitting the coherent optical signal emanating from the output of the laser means into first and second coherent optical signals, the beam splitting means having an output coupled to an input of the first frequency shifter means and an output coupled to the input of the second frequency shifter means;

directional coupler means for coupling the first and the second coherent optical signals into the waveguide, the coupler means having two inputs and two outputs and being optically coupled to the waveguide, the first input of the coupler means being coupled to the output of the first frequency shifter means and the second of the input of the coupler means being coupled to the output of the second frequency shifter means, the directional coupler means and the waveguide being configured with the first and the second frequency shifter means such that the first and the second coherent optical signals are oppositely directed in the waveguide and have frequencies F1 and F2, respectively; and,

bi-cell detector means having two inputs, two outputs and including two detector cells, each input being coupled to a respective output of the directional coupler means whereby the first detector cell receives a portion of the first coherent optical signal travelling in the first direction in the waveguide, and the second detector cell receives a portion of the second coherent optical signal travelling in the second direction in the waveguide.

13. The laser gyroscope as set forth in claim 12 wherein the first detector cell outputs a first detection signal representative of the intensity of the first coherent optical signal in the waveguide, and wherein the second detector cell outputs a second detection signal representative of the intensity of the second coherent optical signal in the waveguide.

14. The laser gyroscope as set forth in claim 12 wherein the directional coupler means has a double-concave geometry.

15. The laser gyroscope as set forth in Claim 13 and further comprising:

a first demodulation network having two inputs and an output, the first of the inputs being coupled to the first detection signal, the second of the inputs being coupled to a modulation signal, the output being coupled to an input of the first signal generating means; and,

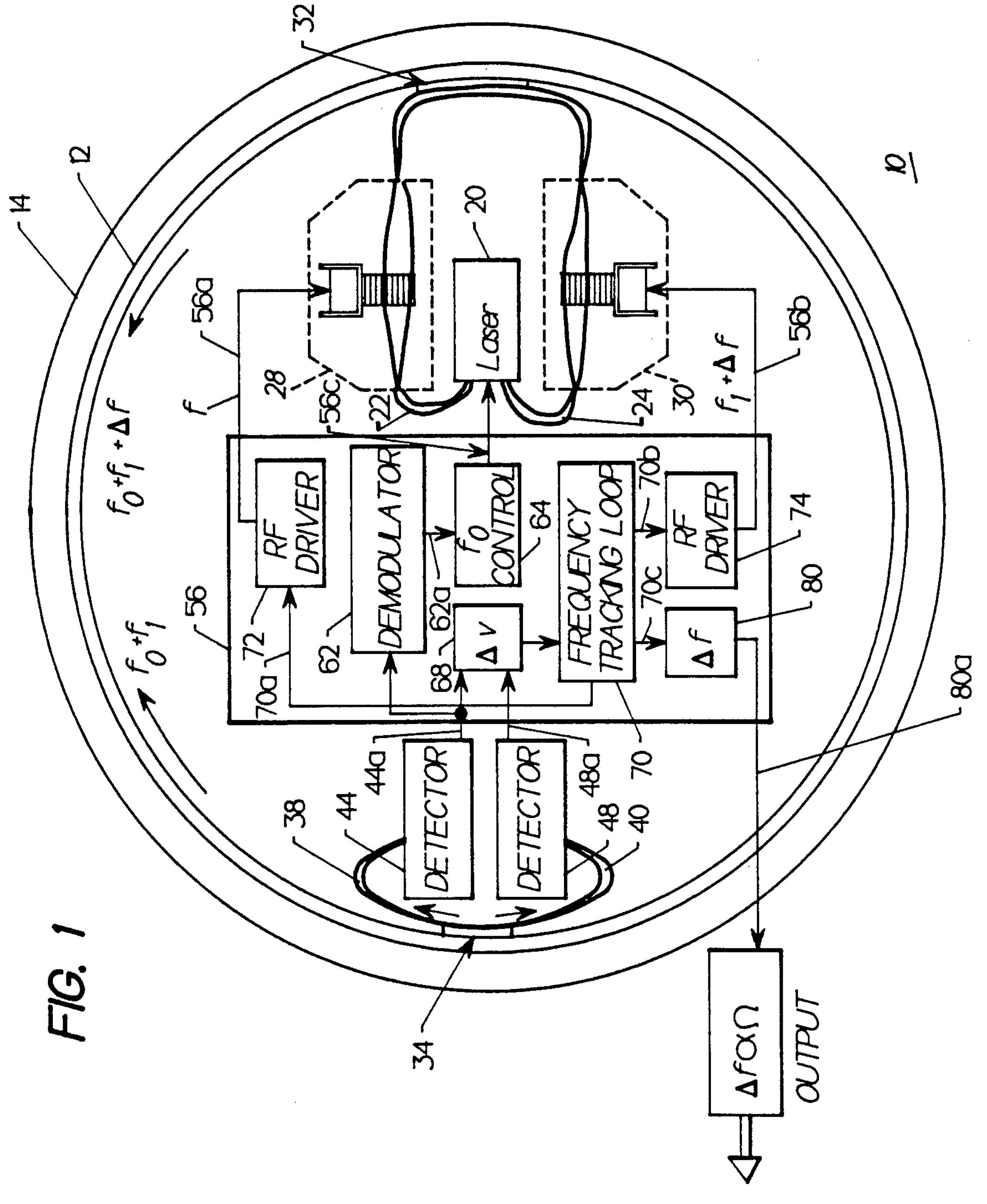
a second demodulation network having two inputs and an output, the first of the inputs being coupled to the second detection signal, the second of the inputs being coupled to the modulation signal, the output being coupled to an input of the second signal generating means.

16. The laser gyroscope as set forth in claim 13, further comprising frequency comparison means having two inputs and an output, the first of the inputs being coupled to the output of the first signal generating means, the second of the inputs being coupled to the output of the second signal generating means, the frequency comparison means generating a rate signal representative of the difference in frequency between the output signal of the first and second generating means, whereby the rate signal is representative of the angular rate of the waveguide.

17. The laser gyroscope as set forth in claim 12 wherein the first and second frequency shifter means each include an acousto-optical modulator.

18. The laser gyroscope as set forth in claim 12 wherein the first and second signals generated by the first and the second signal generator means, respectively, are radio-frequency signals.

19. The laser gyroscope as set forth in claim 12 wherein the waveguide is a thin film circular waveguide and wherein the directional coupling means, the first and second frequency shifter means, the laser means, the first and second signal generating means, the first and second demodulation networks, and the bi-cell detector means are all located within the perimeter of the waveguide.


14
12
32
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20
Laser
28
30
22
24
56a
56b
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f
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$f_0 + f_1$
56
RF DRIVER
72
70a
DEMODULATOR
62
62a
f_0 CONTROL
64
Δv
68
FREQUENCY TRACKING LOOP
70
70b
70c
RF DRIVER
74
Δf
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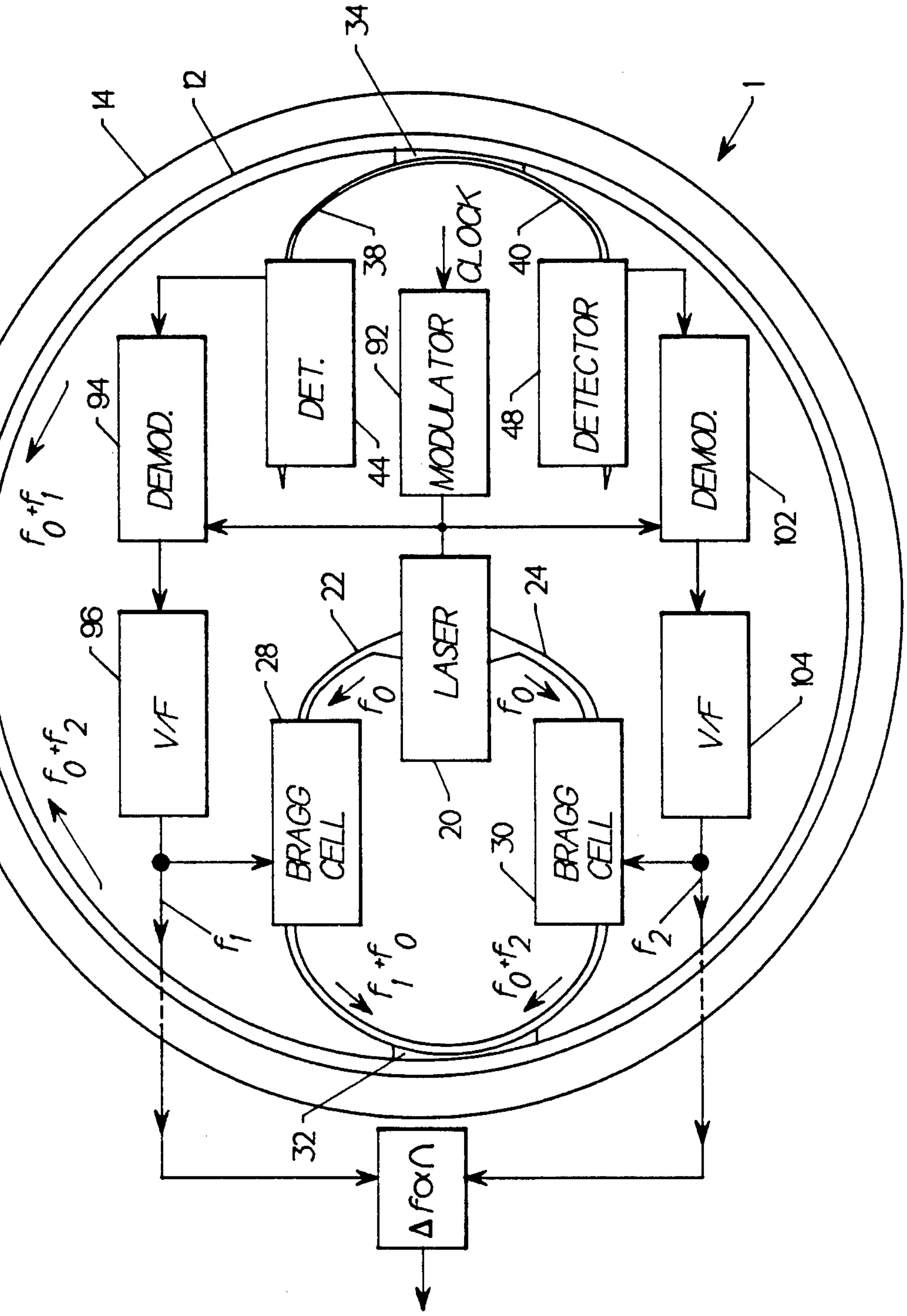
$\Delta f \propto \Omega$
OUTPUT

FIG. 1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104
28
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BRAGG CELL
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Δ f∝Ω

FIG. 2

FIG. 3

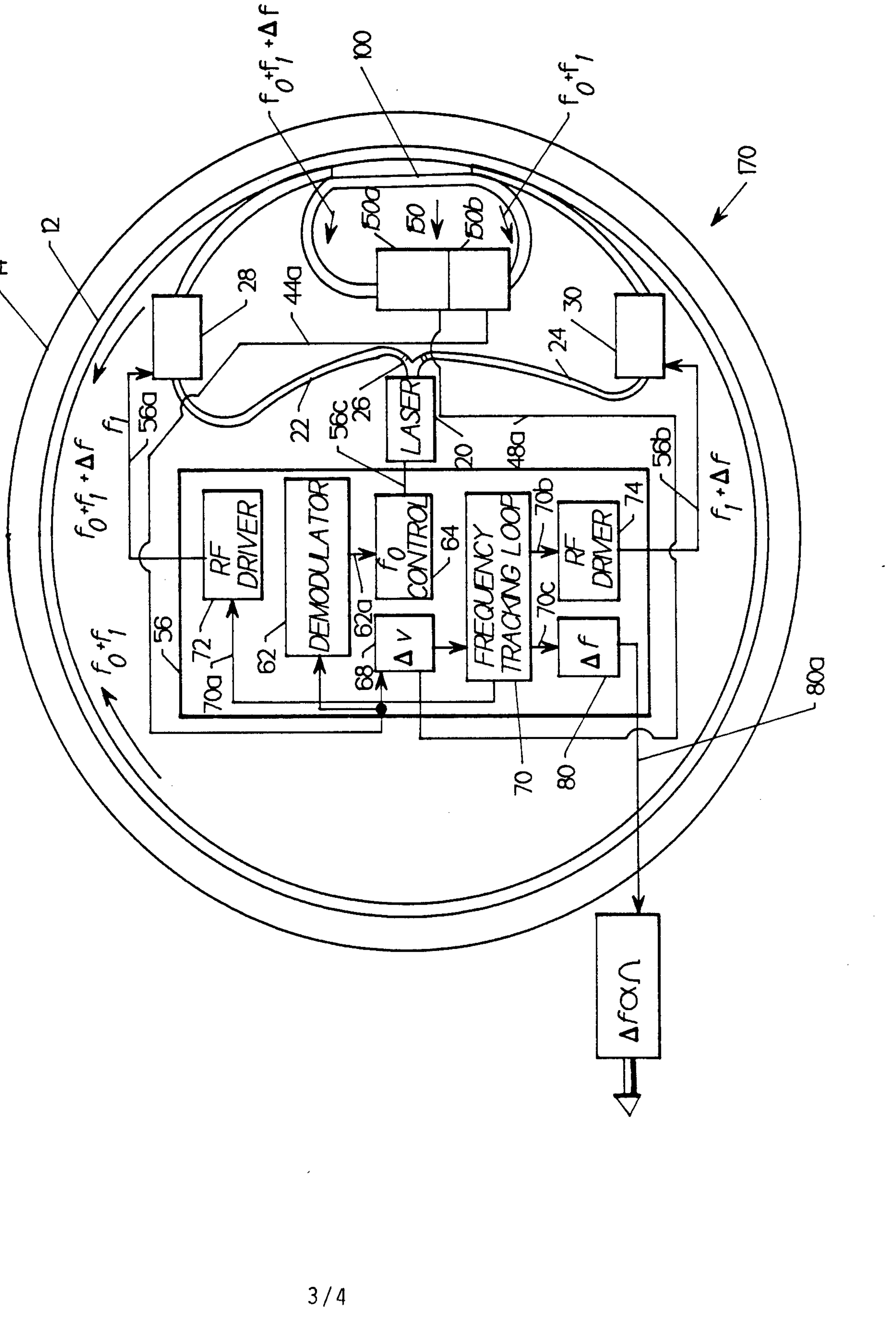
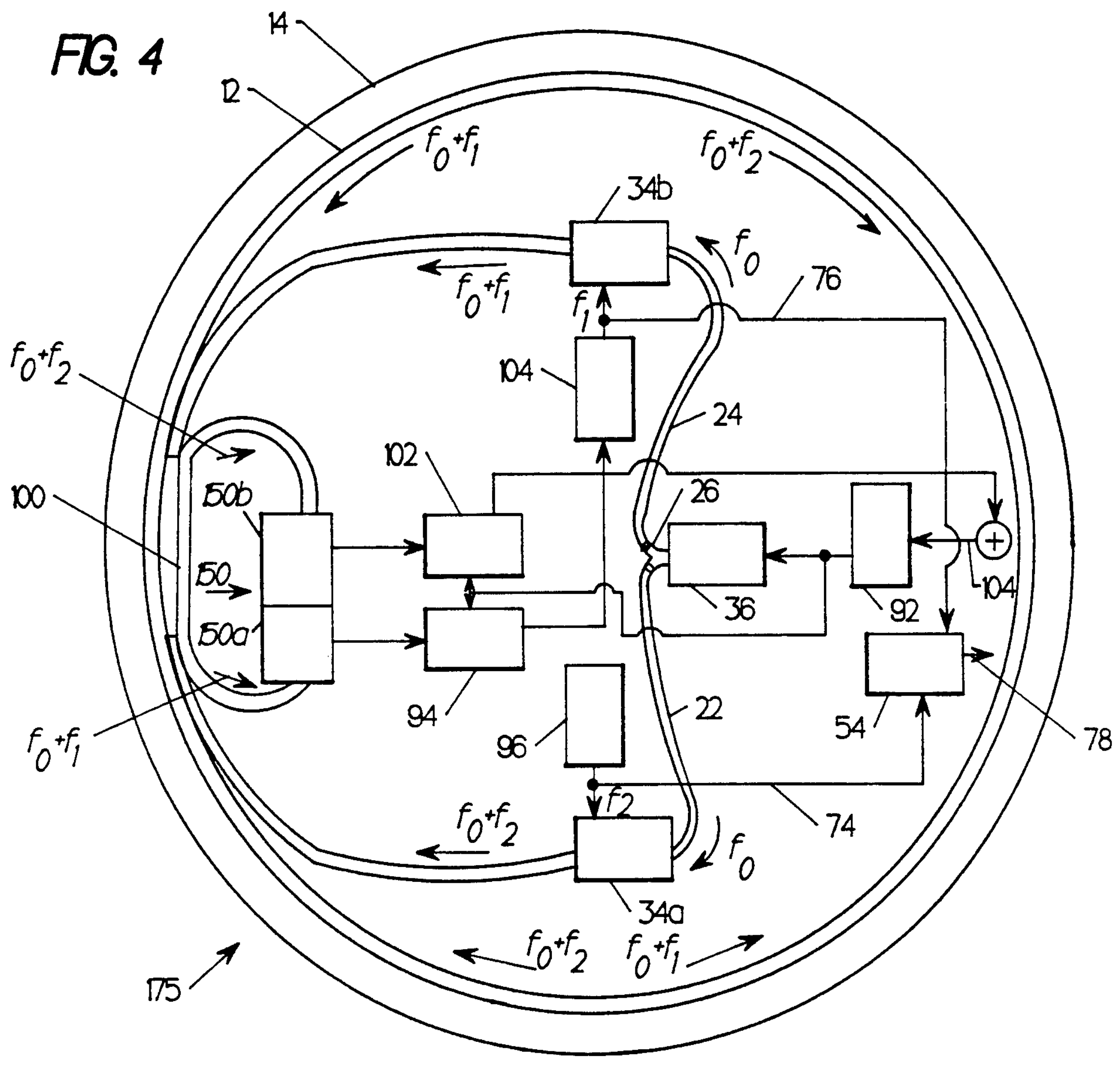

RF DRIVER
DEMODULATOR
f_0 CONTROL
LASER
FREQUENCY TRACKING LOOP
RF DRIVER
Δ v
Δ f
Δf∝Ω
$f_0+f_1+\Delta f$
f_0+f_1
f_1
$f_1+\Delta f$
$f_0+f_1+\Delta f$
f_0+f_1
12
14
20
22
24
26
28
30
44a
48a
56
56a
56b
56c
62
62a
64
68
70
70a
70b
70c
72
74
80
80a
100
150
150a
150b
170

FIG. 4


14
12
f_0+f_1
f_0+f_2
34b
f_0
76
f_1
104
24
102
26
100
150b
150
150a
36
92
104
94
96
22
54
78
f_2
74
34a
175

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 93/05722

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01C19/72

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
Y	US,A,4 514 088 (J.D. COCCOLI) 30 April 1985 cited in the application see abstract; figure 2 see column 3, line 37 - column 4, line 29	1-7
A		11,12

Y	EP,A,0 268 444 (BRITISH AEROSPACE PLC) 25 May 1988 see column 3, line 2 - column 3, line 27; figure 4A	1

Y	US,A,5 059 030 (S.M. ARNOLD) 22 October 1991 see the whole document	1-7

A	US,A,4 678 334 (G.T. COATE ET AL) 7 July 1987 see abstract; figure 3	1-7,11, 12

	-/--	

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

2 **IV. CERTIFICATION**

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21 SEPTEMBER 1993	30 DC 93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	HUNT J.H.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 93/05722

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	EP,A,0 026 066 (NORTHROP CORP) 1 April 1981 cited in the application see abstract; claim 1; figures 1,2 -----	1-7,11, 12

Form PCT/ISA/210 (extra sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9305722 SA 76332

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 21/09/93
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4514088	30-04-85	None	
EP-A-0268444	25-05-88	DE-A- 3776088	27-02-92
		JP-A- 2103975	17-04-90
		US-A- 4820008	11-04-89
US-A-5059030	22-10-91	None	
US-A-4678334	07-07-87	None	
EP-A-0026066	01-04-81	US-A- 4326803	27-04-82
		JP-B- 1010957	22-02-89
		JP-C- 1530884	15-11-89
		JP-A- 56054312	14-05-81

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82