advantageous for the teeth to be constructed as portions of arcs from concentric circles.

As previously mentioned, drive system 310 induces oscillations of proof mass 302 about the Z-axis. The drive system 310 includes one or more drive electrodes 350a-350b and one or more feedback electrodes 352a-352b connected to substrate 304. Preferably, the drive and feedback electrodes are arranged in opposing pairs located on either side of each inner comb 330a-330d. Each feedback and drive electrode includes a plurality of teeth 354 which are interdigited with teeth 334 of the adjacent inner comb. Teeth 354 may have an arc length of approximately twenty microns and a width of approximately two microns. The drive electrodes of drive system 310 act as electrical, mechanical transducers. By application of an alternating voltage between the drive electrodes and the proof mass, the proof mass may be forced to oscillate about the Z-axis. Specifically, beams 320 may flex or bend so that rotor 316 may rotate.

Referring to FIG. 18, dual-axis gyroscopic sensor 300 includes a transresistance amplifier 366 which produces drive signals 362 and 364 having a driving frequency ω_z of about twenty to thirty kilohertz. Drive signals 362 and 364 are equal in magnitude but opposite in sign. phase-locked loop 360. A phase-locked loop 360 generates an extremely accurate digital output signal on line 368 which is in phase with the rotational rate of the proof mass. The opposing feedback electrodes 352a and 352b are connected to the positive and negative inputs of trans-resistance amplifier 366. The opposing drive electrodes 350a and 350b are connected to the positive and negative outputs 362 and 364 of trans-resistance amplifier 366 and to phase-locked loop 360.

The positive and negative outputs of trans-resistance amplifier 366 are also mixed with the digital output signal on line 368 by a mixer 370. The output of mixer 370 is then used to modulate trans-resistance amplifier 366. This modulation provides an automatic gain control circuit to control the amplitude of the oscillations of proof mass 302. Thus, drive system 310 provides a phase-locked oscillation of constant amplitude to the proof mass and provides a clean signal for Coriolis demodulation.

Returning to FIG. 17A, sensing system 312 includes four sense electrodes 374a-374d (shown in phantom because they are located beneath the rotor 316). Each sense electrode is shaped as a quarter-pie section and may be formed of an n+ diffused region in substrate 304. Sense electrodes 374a and 374c are positioned along the X-axis whereas the sense electrodes 374b and 374d are positioned along the Y-axis. The Coriolis oscillation is measured by sensing the change in capacitance between rotor 316 and sense electrodes 374a-374d. For example, if the gyroscopic sensor rotates about the Y-axis, then the Coriolis force may cause the right portion of rotor 316 to move closer to sense electrode 374b and the left portion of rotor 316 to move farther away from sense electrode 374d. Thus, the capacitance between sense electrode 374b and rotor 316 increases whereas the capacitance between sense electrode 374d and rotor 316 decreases. Because each pair of opposing sense electrodes provides differential sensing, translation of the rotor up or down along the Z-axis does not change in sense output.

Referring to FIG. 18, a first sense voltage source 376 connects opposing sense electrodes 374a and 374c, and

a second sense voltage source 378 connects opposing sense electrodes 374b and 374d. The sense voltage sources 376 and 378 generate AC voltages with different modulation frequencies. For example, one voltage source may operate at 200 kHz and the other voltage source may operate at 300 kHz. In order to extract the position signals indicating the angular position of rotor 316 about the X-axis and Y-axis, proof mass 302 is electrically connected to an integrator 380. The integrator 380 may include a capacitor 381 having a capacitance of about 50 femtoFarrads. A benefit of integrator 380 is that it improves linearity.

The output of integrator 380 is demodulated with the signal from sense voltage source 376 by a mixer 382. The output from integrator 380 is also demodulated with the signal from sense voltage source 378 by a mixer 384. The outputs of mixers 382 and 384 are then demodulated by mixers 386 and 388 with the digital output signal on line 368 from phase-locked loop 360. The output of mixer 386 provides the angular rotation rate of the gyroscopic sensor about the X-axis, and the output of mixer 388 provides the rotation rate of the gyroscopic sensor about the Y-axis.

The combined mechanical and electrical sensitivity of dual-axis gyroscopic sensor 300 may be calculated according to the following equation:

$$\left|\frac{V_{out}}{\Omega_y}\right| = \left|\frac{\theta_x}{\Omega_y}\right|\left|\frac{V_{out}}{\theta_x}\right| = \left|\frac{2\theta_{z0}\omega_z}{\omega^{2}_{x} + \frac{j\omega_x\omega_z}{Q_x} - \omega^{2}_{z}}\right|\left|2\frac{\partial C}{\partial\theta_x}\frac{V_s}{C_I}\right| \qquad (19)$$

were V_s is the sense voltage, C_i is the capacitance of the integrating capacitor, Q_x is the quality of inverse

damping coefficient, and V_{out} is the voltage signal from the mixer. One drawback of the sensing system is that a small inherent voltage is generated at twice the drive frequency. However, this voltage is far from the sense modulation frequencies.

As described above, if dual-axis gyroscopic sensor 300 is rotating about an axis parallel to the surface of the substrate, then the oscillation of rotor 316 about the Z-axis induces an oscillation about the X-axis or Y-axis due to the Coriolis force. In an ideal device, rotor 316 is perfectly aligned so that the only motion caused by drive system 310 is within the X-Y plane. However, fabrication imperfections may cause rotor 316 to wobble as it undergoes rotation about the Z-axis. Specifically, even if the gyroscopic sensor 300 is not rotating about the X-axis or Y-axis, as rotor 316 rotates about the Z-axis, it may oscillate or wobble out of the X-Y plane. The wobble caused by the fabrication imperfections generates a false rotation rate measurement called quadrature error. The quadrature error in dual-axis gyroscopic sensor 300 is similar to the quadrature error in Z-axis gyroscopic sensor 20; the quadrature error and Coriolis acceleration are both sinusoidal signals centered at the frequency of oscillation and ninety degrees out of phase. Ideally, demodulation will eliminate the out-of-phase quadrature error. However, because the electronic components may have a small phase-lag, some percentage of the quadrature error will corrupt the measurement of the rotation rate.

Returning to FIG. 17A, quadrature correction system 314 includes eight correction electrodes 390a-390h. The correction electrodes are arranged in pairs with each outer comb 340a-340d surrounded by two opposing

correction electrodes. For example, outer comb 340a is flanked by correction electrodes 390a and 390b. Each correction electrode has a plurality of teeth 392 which are interdigitated with the teeth of the outer combs. The quadrature correction system 314 may apply voltages to the correction electrodes 390a-390h in order to levitate teeth 344 of the outer combs and cancel the quadrature error.

Returning to FIG. 18, each pair of opposing correction electrodes may be connected to a DC offset voltage source. In addition, the correction electrodes on opposite sides of the rotor may be connected. For example, correction electrode 390a may be electrically connected to correction electrode 390f. A first DC voltage source 394 may connect electrode 390a to electrode 390b, and second DC voltage source 396 may connect correction electrode 390c and 390d. The DC offset may be selected to electrostatically levitate outer combs 340a-340d and thereby cancel the quadrature error.

Referring to FIG. 19, a portion of substrate 304 beneath teeth 344 and 392 may be an n+ diffused region to provide a control pad electrode 398. The control pad electrode 398 is electrically connected to proof mass 302. By applying a generally positive voltage to teeth 392 and a generally negative voltage to teeth 344 and control pad electrode 398, the electric field (shown by field lines 399) generates an upward force F_z on teeth 344.

Returning to FIG. 17A, the correction electrodes 390a and 390f generate an upward force on the teeth on the left side of the rotor which is stronger than the upward force on the teeth on the right side of the rotor

generated by electrodes 390b and 390e. This force imbalance creates a balancing torque which tends to rotate the rotor so that, absent the Coriolis force, it vibrates solely in the X-Y plane. Because the quadrature error results in a linear displacement, the balancing forces need to be proportional to the position of the proof mass about the Z-axis. The balancing torque F_z is proportional to the overlapping area between teeth 344 and teeth 392. Because the overlapping area between teeth 344 and teeth 392 is directly proportional to the angular position of rotor 316, the balancing torque will also be proportional to the angular position of the rotor.

Referring to FIG. 20, another embodiment of dual-axis gyroscopic sensor 300' includes a modified quadrature correction system 314'. In quadrature correction system 314', four generally rectangular or wedge-shaped plates 340a'-340d' are connected to outer edge 326 of rotor 316. Two fixed electrode pads 390a' and 390b' are disposed on substrate 304 beneath each plate. The fixed electrode pads 390a' and 390b' may be formed of n+ diffused regions in the substrate. A DC offset voltage may be applied between each pair of electrode pads to correct the quadrature error. For example, a positive offset voltage may be applied so that the voltage of electrode pad 390b' is higher than the voltage of electrode pad 390a'. As rotor 316 rotates counter-clockwise and the plate 340a' moves rightwards, more of the plate will overlap electrode pad 390b', and thus the right side of the plate will be more attracted to the substrate than the left side of the plate. This will generate a torque which tends to rotate rotor 316 about the X-axis. The dual-axis gyroscopic sensor 300'

otherwise functions in a manner similar to dual-axis gyroscopic sensor 300.

Referring to FIG. 21, in a gyroscopic sensor 400 the drive system, the sensing system, and the quadrature correction system use a single set of electrodes. Gyroscopic sensor 400 includes a proof mass 402 connected to a substrate 404 by a flexible suspension 406. A plurality of opposing electrode fingers 410a and 410b (only two opposing fingers are shown) project from proof mass 402 along the X-axis. Each electrode finger 410a is flanked by respective stationary electrode fingers 412a and 414a. Similarly, each electrode finger 410b is flanked by stationary electrode fingers 412b and 414b.

To sense the position of the proof mass along the Y-axis, a voltage source 420 applies a high-frequency (e.g., one megahertz) AC voltage between upper electrode fingers 412a, 412b and lower electrode fingers 414a, 414b. Proof mass 402 is electrically connected to an integrator 422. The output of integrator 422 provides a position signal.

To drive the proof mass along the X-axis, a voltage-controlled oscillator 426 is connected to apply an AC voltage with a frequency ω between the opposing electrode fingers 412a, 414a and 412b, 414b. The output of integrator 422 is applied to a phase-sensing circuit 428, and the output of phase-sensing circuit 428 controls the voltage-controlled oscillator 426.

The output voltage V_{out} from integrator 422 is

$$V_{out} = \frac{Q_{struct}}{C_I} \qquad (20)$$

where Q_{struct} is the charge on the proof mass and C_I is the capacitance of integrator 422. Q_{struct} is given by the equation:

$$Q_{struct} = \frac{dC_s}{dy}\Delta y V_{sense} + \Delta C_x(t) V_F(t) \quad (21)$$

where $V_F(t)$ is AC portion of the forcing voltage, $C_x(t)$ is the changing capacitance on the forcing electrodes as the structure displaces along the X-axis, and V_{sense} is the sense voltage applied by voltage source 420. Combining Equations 20 and 21 yields:

$$V_{out} = \frac{\Delta C_x(t) V_F(t)}{C_I} + other\ terms \quad (22)$$

If the forcing voltage $V_F(t)$ is $V_F \sin(\omega t)$ then the resulting displacement $x(t)$ is given by the following equation:

$$x(t) = X_0(\omega, \omega_x)\sin(\omega t + \phi(\omega, \omega_x)) \quad (23)$$

where ω is the drive frequency, ω_x is the driven mode resonance frequency, $X_0(\omega, \omega_x)$ is the amplitude, and $\phi(\omega, \omega_x)$ is a phase difference. Because $\Delta Cx(t)$ is proportional to $x(t)$,

$$V_{out} = \frac{\Delta C_x(\omega, \omega_x)}{C_I}\sin(\omega t + \phi(\omega, \omega_x))\sin(\omega t) \quad (24)$$

and therefore

$$V_{out} = \frac{\Delta C_x(\omega, \omega_x)}{2C_I}[\cos(\phi(\omega, \omega_x)) - \cos(2\omega t + \phi(\omega, \omega_x))] \quad (25)$$

When the drive frequency ω is equal to the resonant frequency ω_x, the phase ϕ will be 90°. Because

the $\cos(\phi(\omega,\omega_{x1})$ term of Equation 25 produces a DC offset, phase-sensing circuit 428 can drive the frequency ω of voltage-controlled oscillator 426 to the resonant frequency ω_x by sensing when there is no DC offset. Thus, the drive voltage will remain phase locked with the position of the proof mass.

Quadrature error correction may be accomplished in gyroscopic sensor 400 by applying a DC voltage between electrode fingers 412a and 414a and an equal but opposite DC voltage between electrode fingers 412b and 414b.

Referring to FIG. 22, a micromachined gyroscopic sensor 500 may be fabricated using high-aspect-ratio single-crystal-silicon micromachining techniques to produce an extremely thick device. Gyroscopic sensor 500 includes a vibratory structure 502 connected to a rigid frame or substrate 504 at anchor points 511. Structure 502 is configured to vibrate in a plane parallel to a surface 505 of the substrate. As such, a gap of about 0.5 to 4.0 microns, such as about 1.0 microns, separates the vibratory structure from surface 505.

Structure 502 is generally H-shaped, and includes a proof mass portion 506 and a flexible suspension portion 508. The suspension portion includes two parallel crossbeams 516 and four parallel flexures 510 positioned generally along the X-axis. One end of each flexure is connected to anchor 511 which connects structure 502 to the substrate, and the other end of each flexure is connected to one of crossbeams 516. The total length of one crossbeam 516 and two flexures 510 may be about 200 to 1500 microns in length, preferably about 1250 microns.

Proof mass portion 506 includes two crossbars 512 connected to two beams 514 to provide a generally square

arrangement. Three additional crossbars 512 are also connected between beams 514. A plurality of electrode teeth or fingers project along the X-axis from the crossbars 512. Four additional flexures 518 may connect flexures 510 to proof mass portion 506.

Structure 502 may be formed of single-crystal silicon. The structure 502 may have a thickness T of at least 25 microns, and it is advantageous for the thickness T to be at least 50 microns. The thickness may be between about 50 and 100 microns, but for some applications the thickness may be 250 microns. The flexures of the structure may have a width W_F of about two to five microns. The aspect ratio, i.e., the ratio of width to thickness, of the flexures should be greater than 10:1, and it is advantageous for the aspect ratio to be greater than 20:1. The aspect ratio may even be 50:1 or more. The beams and crossbars of the proof mass portion may have a width W_B of about five to ten microns. The total mass of structure 502 may be about 10 to 50 micrograms.

The suspension portion 508 is designed to be flexible along the X-axis and Y-axis and rigid to other modes of vibration. In particular, the high-aspect ratio of the flexures results in a structure which is very rigid to torsion and Z-axis acceleration.

Referring to FIG. 23, the micromachined gyroscopic sensor 500 includes four major electronic elements: a drive system 520 used to sustain oscillation of structure 502 along the X-axis, a sensing system 540 used both to detect deflections of structure 502 along the Y-axis, a sense tuning system 560 used to adjust the resonant frequency of structure 502 along the Y-axis, and a

quadrature correction system 580 used to apply electrostatic forces to cancel quadrature error.

As shown in FIGS. 15 and 16, the drive system 520 includes two opposing driving electrode combs 522a and 522b and two feedback electrode combs 524a and 524b, all connected to substrate 504. Each driving electrode comb and feedback electrode comb includes a plurality of electrode teeth or fingers 526 which project along the drive axis and which are interdigited with electrode teeth or fingers 528 which project from structure 502. Electrode teeth 526 and 528 may have a length L of about fifteen microns, and a width W_E of about two to six microns. Electrode teeth 526 may be separated from electrode teeth 528 by a gap of about 2.5 microns. Electrode teeth 526 and 528 may be formed from the same layer of single-crystal silicon and have a thickness of about 100 microns.

The feedback electrodes combs 524a and 524b are electrically connected to the positive and negative inputs of a trans-resistance amplifier 530. The driving electrode combs 522a and 522b are connected to the positive and negative outputs, respectively, of the transresistance amplifier and to a phase-locked loop circuit 532. At least one of the outputs from transresistance amplifier 530 may be mixed with a velocity signal from phase-locked loop 532 by a mixer 534. The output of mixer 534 is then used to modulate transresistance amplifier 530 to provide an automatic gain control circuit to control the oscillation amplitude of structure 502.

The sensing system 540 includes an opposing pair of sense electrode combs, including left sense electrode combs 542a and 542b, and right sense electrode combs 544a

and 544b. The left sense electrode combs 542a, 542b include a plurality of "left" electrode teeth 546, and the right sense electrode combs 544a, 544b include a plurality of "right" electrode teeth 548. The electrode teeth 546 and 548 are interdigited with electrode teeth 550 which project from structure 502 such that each electrode tooth 550 is disposed between one left tooth 546 and one right tooth 548.

Electrode teeth 546, 548 and 550 may have a length L of about fifteen microns, and width W_E of about two to six microns. Electrode teeth 546, 548 and 550 have a thickness of at least 25 microns, and the thickness may be between about 50 and 100 microns. The aspect ratio of the electrode teeth should be at least about 5:1. The aspect ratio may be at least 10:1, and it may be between about 10:1 and 20:1. Electrode teeth 550 may be separated from electrode teeth 546 and 548 by a gap having a width W_G between about 0.5 and 4.0 microns, such as 2.5 microns. The aspect ratio of the gap should be at least 10:1, and it may be greater than 20:1 or even greater than 50:1. Electrode teeth 546, 548 and 550 may be formed from the same layer of single-crystal silicon in the same fabrication step so that the teeth are coplanar.

A first sense voltage source 552 applies an AC voltage to left sense electrode combs 542a and 542b. A second sense voltage source 554 applies an AC voltage, 180° out of phase with the first sense voltage, to right sense electrode combs 544a and 544b. The sense voltage sources may generate AC signals having a maximum voltage of about 0.1 to 5.0 volts and a frequency of about 0.1 to 5.0 megahertz. The AC signals may have a voltage amplitude of one volt and a frequency of one megahertz.

To measure the Coriolis signal Ω_z, structure 502 is electrically connected to an integrator 556, and the output of integrator 556 is amplified by an AC amplifier 558. The signal from one of the sense voltage sources is mixed with a position signal from phase-locked loop 532 by a mixer 536. The output of mixer 536 is then mixed with the output of amplifier 558 by a mixer 538 to generate the Coriolis signal.

Tuning of the Y-axis resonant frequency may be accomplished sense tuning system 560 applying a DC bias voltage between a set of inner tuning electrodes 562 and outer tuning electrodes 564. Electrodes 566 project from structure 502 and are interdigited with the inner tuning electrodes 562 and outer tuning electrodes 564. A tuning voltage source 568 applies a bias voltage $V_{\Delta fy}$ between inner tuning electrodes 562 and outer tuning electrodes 564. Alternately, the Y-axis resonant frequency could be tuned by applying a DC bias between the vibratory structure and the tuning electrodes.

Quadrature error cancellation is accomplished by applying a voltage between diagonal pairs of electrodes. The quadrature error correction system 580 includes a lower left electrode 582a, an upper left electrode 582b, a lower right electrode 584a, and an upper right electrode 584b. Lower left electrode 582a is connected to upper right electrode 584b, and upper left electrode 582b is connected to lower right electrode 584a. A quadrature correction voltage source 586 applies a bias voltage $2V_{Quad}$ between the electrode pairs 582a, 584b and 582b, 584a. The bias voltage creates a balancing force which is proportional to the position of the proof mass along the X-axis. This bias voltage may be determined

experimentally (as shown in FIG. 13) and may be in the range of 1 mV to 100 mV.

In addition, quadrature error correction system 580 may include a feedback loop to automatically adjust the bias voltage. A velocity signal from phase-locked loop 532 may be mixed with a signal from one of the sense voltage sources by a mixer 590. The output of mixer 590 may be mixed with the output of amplifier 558 by a mixer 592. The output of mixer 592 may be used to control the voltage source 586.

Assuming that the mass M of structure 502 is 36 micrograms, the drive and sense frequencies ω_x and ω_y are each 63 kHz, the quality factor Q for single-crystal silicon is 200,000 (about three to four times higher than that of polysilicon), and the amplitude X_0 of the drive mode is five microns, then one may calculate from Equation 16 that, at room temperature, the Brownian noise Ω_{nB} for a bandwidth (BW) of 60 Hz is about 2 deg/hr.

The electronic noise floor is determined by the thermal noise level in charge integrator 556. Where the sense frequency ω_y is electrostatically tuned to the drive frequency ω_x plus an offset frequency $\Delta\omega$, the electronic noise Ω_{nE} may be calculated from the equation:

$$\Omega_{nE} = 2\frac{g_0\Delta\omega}{X_0 V_S}\sqrt{\frac{32}{3\pi}\left(\frac{k_B T}{C_S}\right)\frac{1}{f_T}\left(\left(1+\frac{C_P}{C_S}\right)BW\right.} \qquad (26)$$

where g_0 is the sense-capacitor gap width, X_0 is the oscillation amplitude, V_S is the sense voltage, k_B is Boltzmann's constant, T is the temperature, C_S is the sense capacitance, C_P is the parasitic capacitance, f_T is the CMOS transition frequency, and BW is the bandwidth.

Assuming that the sense-capacitor gap g_0 is 2.5 microns, the sense voltage V_S is 1 V, C_S is the sense capacitance C_S is 1.25 pF, the parasitic capacitance C_P is 0.25 pF, and the CMOS transition frequency f_T is 1 GHz, one may calculate from Equation 18 that a frequency offset $\Delta\omega$ of 2π(175 Hz) is required to make the electronic noise floor equal to 2.5 deg/hr. This degree of tuning is feasible in principle because the measurement bandwidth is about 60 Hz.

By increasing the thickness of electrode teeth 546, 548 and 550, the surface area between the stationary and movable electrodes is increased, resulting in a larger sense capacitance. The larger sense capacitance reduces electronic noise. Similarly, the thicker structure is more massive and thus less subject to Brownian motion. In short, a gyroscopic sensor using high-aspect-ratio single-crystal silicon structures may be about one-hundred times more sensitive than a gyroscopic sensor using structures formed of thin polysilicon layers.

Fabrication of gyroscopic sensor 500 includes six basic steps: handle wafer processing, device wafer processing, bonding, CMOS processing of the bonded structure, etching to form the vibratory structure and stationary electrodes, and capping.

Referring to FIG. 24A, processing of a bottom substrate 600 may begin with a handle wafer 602, which may be a single-crystalline silicon substrate. Handle wafer 602 is oxidized to form an oxide layer 604, and a polysilicon layer 606 is deposited on oxide layer 604. Polysilicon layer 606 is then doped, polished and patterned to form the interconnects for the electrically isolated electrodes 522a, 522b, 524a, 524b, 542a, 542b,

544a, 544b, 562, 564, 582a and 584b, and 582b and 584a, of the gyroscopic sensor.

Referring to FIG. 24B, processing of a top substrate 610 may begin with a device wafer such as a silicon-on-insulator (SOI) substrate. The device wafer includes an oxide layer 616 sandwiched between two single-crystal silicon layers 614 and 618. A shallow trench 620 is formed in a surface 622 of single-crystal silicon layer, except in regions 624. Regions 624 will form anchors 511 connecting vibratory structure 502 to substrate 504. Trench 620 may be formed by deposition of a photoresist mask, etching of the exposed portions of single-crystal silicon layer 614, and removal of the mask. Alternately, trench 620 may be formed by mechanical thinning.

The thickness of single-crystal silicon layer 614 will define the thickness of vibratory structure 502, and the depth of trench 620 will define the spacing between the vibratory structure and the substrate. Preferably, single-crystal silicon layer 614 is about 100 microns thick, and trench 620 is about one micron deep.

Referring to FIG. 24C, bottom substrate 600 and top substrate 610 are aligned with surface 622 of top substrate 610 abutting the patterned polysilicon layer 606 of bottom substrate 600. The top and bottom substrates are bonded so that trench 620 forms a sealed cavity 626 between the two substrates. Then, referring to FIG. 24D, top substrate 610 is thinned by etching or mechanical removal of single-crystal silicon layer 618 to expose oxide layer 616, and oxide layer 616 is stripped. At this point, the bonded assembly is ready for standard CMOS processing. Because sealed cavity 626 is completely internal, the bonded assembly appears as an unprocessed

silicon wafer and may processed with conventional techniques.

Referring to FIG. 24E, the integrated circuitry of gyroscopic sensor 500 is fabricated on an exposed surface 630 of single-crystal silicon layer 614 in device regions 632. Following circuit fabrication, a thermocompression bond layer 634 is deposited and patterned. The bond layer 634 may be a conductive metal, such as gold.

Referring to FIG. 24F, the structures of the gyroscopic sensor are formed in single-crystal silicon layer 614. A photoresist mask is deposited over bond layer 634 and exposed surface 630, and the photoresist mask is patterned to define the gaps between the vibratory structure 502 and the stationary electrodes (not shown in this cross-sectional view). The single-crystal silicon layer 614 is etched using inductively-coupled plasma based deep reactive ion etching until cavity 626 is exposed. The etching step forms trenches 636 which create the free-standing vibratory structure and the various electrode structures of the gyroscopic sensor. Following the reactive ion etching, an oxygen plasma may be used to remove the photoresist mask, and the assembly may undergo a UV-ozone clean.

Finally, referring to FIG. 24G, a capping wafer 640 is aligned and bonded to top substrate 610. Capping wafer 640 may be glass or oxidized silicon. An underside 642 of the capping wafer may include a patterned thermocompression bond layer 644. Bond layer 634 may be aligned with bond layer 644, and the thermocompression bond may be formed by the application of a pressure of approximately 20 psi and a temperature of about 300-350°C for several minutes. The capping wafer may also include

an etched hole 646 that permits access to bonding pads 648 in device regions 632.

The present invention has been described in terms of a preferred embodiment. The invention, however, is not limited to the embodiment depicted and described. Rather, the scope of the invention is defined by the appended claims.

What is claimed is:

1. A microfabricated structure comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers, coplanar with said first plurality of electrode fingers, connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said first third plurality of electrode fingers being coplanar with said first and second plurality of electrode fingers and projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers.

2. The structure of claim 1 further comprising a voltage source to apply a voltage between said second and third plurality of electrode fingers.

3. The structure of claim 1 further comprising

a fourth plurality of electrode fingers, coplanar with said first, second and third plurality of electrode

fingers, projecting from said mass along said first axis, and

a fifth plurality of electrode fingers connected to said substrate but electrically isolated from said second and third plurality of electrode fingers, said fourth and fifth plurality of electrode fingers interdigitated.

4. The structure of claim 3 wherein each of said first plurality of electrode fingers has a first length and each of said fourth plurality of electrode fingers has a second length.

5. The structure of claim 4 wherein said first length is greater than said second length.

6. A microfabricated structure comprising:

a substrate; and

a suspension system to permit a mass to vibrate in a plane parallel to a surface of said substrate, said suspension system including,

first and second substantially parallel beams, each of said first and second beams anchored at both ends to said substrate, and

third and fourth substantially parallel beams, one end of each of said third and fourth beams connected to said first beam and another end connected to said second beam.

7. The structure of claim 6 further comprising a plurality of fingers projecting along an axis substantially parallel to said first and second beams.

8. The structure of claim 6 further comprising

a fifth and a sixth beam, one end of each of said fifth beam and sixth beams connected to said third beam and another end connected to said fourth beam, and

a seventh beam, one end of said seventh beam connected to said fifth beam and another end connected to said sixth beam.

9. The structure of claim 8 further comprising a plurality of fingers projecting from said seventh beam along an axis substantially parallel to said first and second beams.

10. The structure of claim 6 wherein sections of said first and second beams located between said third and fourth beams are substantially rigid to prevent rotation of said mass.

11. A sensor comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said third plurality of electrode fingers projecting substantially along said first axis, said second and third pluralities

of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers;

a position sensor to mesure a deflection of said mass in said plane; and

a voltage source for applying a first DC voltage between said second and third pluralities of electrode fingers to cause said mass to vibrate, absent a Coriolis force, more precisely along said first axis.

12. The sensor of claim 11 further including,

a fourth plurality of electrode fingers projecting from said mass along a first axis in said plane and positioned opposing said first plurality of electrode fingers;

a fifth plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a sixth plurality of electrode fingers connected to said substrate but electrically isolated from said fifth plurality of electrode fingers, said sixth plurality of electrode fingers projecting substantially along said first axis, said fifth and sixth plurality of electrode fingers interdigitated with said third plurality of electrode fingers such that each of said fourth plurality of electrode fingers is adjacent to one of said fifth plurality of electrode fingers and one of said sixth plurality of electrode fingers.

13. The sensor of claim 12 further comprising a second voltage source for applying a second DC voltage between

said fifth and sixth plurality of electrode fingers to cause said mass to vibrate, absent a Coriolis force, more precisely along said first axis.

14. The sensor of claim 13 wherein said second DC voltage is substantially equal in magnitude but opposite in sign to said first DC voltage.

15. The sensor of claim 13 wherein said first plurality of electrode fingers is electrically coupled to said second plurality of electrode fingers.

16. The sensor of claim 13 further comprising a voltage source for applying a third DC voltage between said first and third pluralities of electrode fingers and said second, third, fifth and sixth pluralities of electrode fingers to adjust the resonant frequency of vibrations of said mass along a second axis in said plane perpendicular to said first axis.

17. The sensor of claim 11 wherein the position sensor measures the deflection of said mass along a second axis substantially perpendicular to said first axis and rotation of said mass about a Z-axis perpendicular to said surface and vibration of said mass along said first axis generates a Coriolis force to deflect said mass along said second axis, and wherein the sensor further comprises a signal processor coupled to an output of said position sensor to generate a signal varying with the rate of rotation of said mass about the Z-axis.

18. The sensor of claim 17 further comprising a voltage source for applying an AC voltage between said second and third plurality of electrode fingers.

19. The sensor of claim 18 wherein a voltage is applied between said second and third pluralities of electrode fingers to form a capacitive bridge with said first plurality of electrodes, and said position sensor is coupled to said first plurality of electrodes to detect changes in capacitance when said mass is deflected along said second axis.

20. A sensor comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said first third plurality of electrode fingers projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers; and

a voltage source for applying a DC voltage between said first plurality of electrode fingers and said second and third plurality of electrode fingers to adjust the resonant frequency of vibrations of said mass along a second axis in said plane perpendicular to said first axis.

21. A microfabricated gyroscopic sensor for sensing rotation about a Z-axis, comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a drive system to cause said mass to vibrate substantially along a first axis in said plane;

a first plurality of electrode fingers projecting from said mass substantially along said first axis;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate and projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers;

a position sensor coupled to said first plurality of electrode fingers for measuring the deflection of said mass along a second axis in said plane perpendicular to said first axis, wherein rotation of said mass about a Z-axis perpendicular to said surface and vibration of said

mass along said first axis generates a Coriolis force to deflect said mass along said second axis; and

a signal processor coupled to an output of said position sensor to generate a signal varying with the rate of rotation of said mass about the Z-axis.

22. The sensor of claim 21 further comprising a voltage source for applying an AC voltage having a first frequency between said second and third plurality of electrode fingers.

23. The sensor of claim 22 wherein a voltage is applied between said second and third pluralities of electrode fingers to form a capacitive bridge with said first plurality of electrodes, and said position sensor is coupled to said first plurality of electrodes to detect changes in capacitance when said mass is deflected along said second axis.

24. The sensor of claim 23 wherein said position sensor further includes an integrator to integrate a signal from said first plurality of electrode fingers.

25. The sensor of claim 24 wherein said drive system generates a signal to cause said mass to oscillate along said first axis at a second frequency.

26. The sensor of claim 25 wherein said drive system said signal.

27. The sensor of claim 25 further including a first mixer to mix the signal from said drive system with a signal from said voltage source.

28. The sensor of claim 27 further including a second mixer to mix a signal from said first mixer with an output signal from said position sensor to produce a position quadrature signal.

29. The sensor of claim 27 further including a second mixer to mix a signal from said first mixer with an output signal from said position sensor to produce a Coriolis signal.

30. The sensor of claim 25 further including a mixer to mix an output signal from said position sensor with a signal from said voltage source to produce a position signal.

31. A microfabricated gyroscopic sensor, comprising:

a substrate;

a mass connected to the substrate by a suspension system;

a drive system to cause the mass to vibrate along a drive axis substantially parallel to a surface of the substrate; and

a position sensor to measure a deflection of the mass along a sense axis substantially parallel to the surface of the substrate, wherein rotation of the mass about an axis of rotation substantially perpendicular to the surface of the substrate and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along the sense axis.

32. The sensor of claim 31 further comprising a processor coupled to an output of the position sensor to

generate a signal varying with the rate of rotation of the mass about the axis of rotation.

33. The sensor of claim 31 wherein the position sensor includes a first sense electrode projecting from the mass, a second sense electrode connected to the substrate and positioned on a first side of the first electrode, and a third sense electrode connected to the substrate and positioned on an opposing second side of the first electrode.

34. The sensor of claim 33 wherein the position sensor senses a change in capacitance between the first electrode and the second and third electrodes.

35. The sensor of claim 33 wherein the first, second and third electrodes are substantially coplanar and each electrode has a longitudinal axis substantially aligned with the drive axis.

36. The sensor of claim 31 wherein the drive system includes a first drive electrode projecting from the mass, a second drive electrode connected to the substrate and positioned on a first side of the first electrode, and a third drive electrode connected to the substrate and positioned on an opposing second side of the first electrode.

37. The sensor of claim 35 wherein the drive system applies an alternating voltage between the between the first electrode and the second and third electrodes.

38. The sensor of claim 33 wherein the first, second and third electrodes are substantially coplanar and each electrode has a longitudinal axis substantially aligned with the drive axis.

39. The sensor of claim 31 further comprising a voltage source to apply a voltage between a plurality of correction electrodes connected to the substrate to cause the mass to vibrate, absent the Coriolis force, more precisely along the drive axis.

40. The sensor of claim 31 further comprising a voltage source to apply a voltage between a first tuning electrode connected to the substrate and a second tuning electrode connected to the mass to adjust a resonant frequency of vibrations of the mass along the sense axis.

41. A microfabricated gyroscopic sensor, comprising:

a substrate;

a mass connected to the substrate by a suspension system;

a drive system to cause the mass to vibrate substantially along a drive axis;

a position sensor to measure a deflection of the mass along a sense axis, wherein rotation of the mass about an axis of rotation and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along the sense axis; and

a voltage source to apply a voltage between electrodes connected to the substrate to cause the mass to vibrate, absent the Coriolis force, more precisely along the drive axis.

42. The sensor of claim 41 further comprising a processor coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the axis of rotation.

43. The sensor of claim 41 further comprising a second voltage source to apply a second voltage between electrodes connected to the mass and the electrodes connected to the substrate to adjust a resonant frequency of vibrations of the mass along the sense axis.

44. The sensor of claim 41 wherein the position sensor applies an AC voltage between the electrodes connected to the substrate.

45. The sensor of claim 41 wherein the drive axis and sense axis are substantially parallel to a surface of the substrate and the axis of rotation is substantially perpendicular to the surface of the substrate.

46. The sensor of claim 41 further comprising:

a first plurality of electrode fingers projecting from the mass substantially along the drive axis;

a second plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis; and

a third plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis, the second and third pluralities of electrode fingers interdigitated with the first plurality of electrode fingers such that each of the first plurality of electrode fingers is adjacent to one of the second

plurality of electrode fingers and one of the third plurality of electrode fingers.

47. The sensor of claim 46 further comprising:

a fourth plurality of electrode fingers projecting from the mass substantially along the drive axis and positioned opposing the first plurality of electrode fingers;

a fifth plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis and positioned opposing the second plurality of electrode fingers; and

a sixth plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis and positioned opposing the third plurality of electrode fingers, the fifth and sixth pluralities of electrode fingers interdigitated with the fourth plurality of electrode fingers such that each of the fourth plurality of electrode fingers is adjacent to one of the fifth plurality of electrode fingers and one of the sixth plurality of electrode fingers.

48. The sensor of claim 47 wherein the first, second, third, fourth, fifth and sixth pluralities of electrode fingers are substantially co-planar.

49. The sensor of claim 48 wherein the voltage source applies a first DC voltage between the second plurality and the third plurality of electrode fingers and a second DC voltage between the fifth plurality and the sixth plurality of electrode fingers.

50. The sensor of claim 49 wherein the second DC voltage is substantially equal in magnitude and opposite in sign to the first DC voltage.

51. The sensor of claim 21 further comprising a voltage source for applying a DC voltage between the first plurality of electrode fingers and the second and third pluralities of electrode fingers to adjust a resonant frequency of vibrations of the mass along the second axis.

52. The sensor of claim 21 further comprising a voltage source for applying a first DC voltage between the second and third pluralities of electrode fingers to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

53. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an axis of rotation substantially perpendicular to a surface of the substrate;

causing the mass to vibrate substantially along a drive axis substantially parallel to the surface of the substrate, rotation of the mass about the axis of rotation and vibration of the mass along the drive axis generating a Coriolis force to deflect the mass along a sense axis substantially parallel to the surface of the substrate; and

measuring a deflection of the mass along the sense axis.

54. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an axis of rotation;

causing the mass to vibrate substantially along a drive axis, rotation of the mass about the axis of rotation and vibration of the mass along the drive axis generating a Coriolis force to deflect the mass along a sense axis;

measuring a deflection of the mass along the sense axis; and

applying a voltage between electrode fingers connected to the substrate to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

55. A microfabricated gyroscopic sensor for measuring rotation about an input axis, comprising:

a substrate;

a mass;

a suspension system connecting the mass to the substrate;

a drive system to cause the mass to oscillate substantially about a drive axis;

a position sensor to measure a rotation of the mass about a sense axis, wherein rotation of the mass about the input axis and oscillation of the mass about the drive axis generates a Coriolis force to oscillate the mass about the sense axis;

a plurality of electrodes associated with the substrate; and

a voltage source to apply a voltage between the electrodes to cause the mass to oscillate, in the absence the Coriolis force, more precisely about the drive axis.

56. The sensor of claim 55 further comprising a processor coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the input axis.

57. The sensor of claim 55 further comprising a second voltage source to apply a second voltage between electrodes connected to the mass and the electrodes connected to the substrate to adjust a resonant frequency of oscillations of the mass about the sense axis.

58. The sensor of claim 55 wherein the position sensor applies an AC voltage between the electrodes connected to the substrate.

59. The sensor of claim 55 wherein the drive axis is substantially perpendicular to the surface of the substrate and the input axis and sense axis are substantially parallel to a surface of the substrate.

60. The sensor of claim 59 further comprising:

a first plurality of electrode fingers projecting from the mass;

a second plurality of electrode fingers projecting from the mass;

a third plurality of electrode fingers projecting from the substrate and interdigitated with the first plurality of electrode fingers; and

a fourth plurality of electrode fingers projecting from the substrate and positioned opposing the first plurality of electrode fingers, the fourth plurality of electrode fingers interdigitated with the second plurality of electrode fingers.

61. The sensor of claim 60 further comprising:

a fifth plurality of electrode fingers projecting from the mass;

a sixth plurality of electrode fingers projecting from the mass;

a seventh plurality of electrode fingers projecting from the substrate and interdigitated with the fifth plurality of electrode fingers; and

a eighth plurality of electrode fingers projecting from the substrate and positioned opposing the seventh plurality of electrode fingers, the eighth plurality of electrode fingers interdigitated with the sixth plurality of electrode fingers.

62. The sensor of claim 61 wherein the first, second, third, fourth, fifth, sixth, seventh and eighth pluralities of electrode fingers are substantially co-planar.

63. The sensor of claim 62 wherein the voltage source applies a first DC voltage between the third plurality and the fourth plurality of electrode fingers and a second DC voltage between the seventh plurality and the eighth plurality of electrode fingers.

64. The sensor of claim 63 wherein the second DC voltage is substantially equal in magnitude and opposite in sign to the first DC voltage.

65. The sensor of claim 55 further comprising a first electrode projecting from the mass, a second electrode connected to the substrate and positioned beneath a first portion of the first electrode, and a third electrode connected to the substrate and positioned beneath a second portion of the first electrode.

66. The sensor of claim 55 wherein the mass is substantially ring-shaped.

67. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an input axis;

causing the mass to oscillate substantially about a drive axis, rotation of the mass about the input axis and oscillation of the mass about the drive axis generating a Coriolis force to oscillate the mass about a sense axis;

measuring an oscillation of the mass about the sense axis; and

applying a voltage between electrodes connected to the substrate to cause the mass to oscillate, in the absence of a Coriolis force, more precisely about the drive axis.

68. A microfabricated gyroscopic sensor, comprising:

a substrate having a first plurality of electrode teeth;

a vibratory structure including a second plurality of electrode teeth and a suspension system connecting the second plurality of electrode teeth to the substrate, the second plurality of electrode teeth interdigited with the first plurality of electrode teeth;

a drive system to cause the vibratory structure to oscillate relative to the substrate; and

a position sensor to measure a deflection of the mass caused by a Coriolis force;

wherein the first and second pluralities of electrode teeth have thicknesses substantially greater than their widths.

69. The sensor of claim 68 wherein the suspension system includes a plurality of flexures having an aspect ratio of at least about 10:1.

70. The sensor of claim 68 wherein the first and second pluralities of electrode teeth have an aspect ratio of at least 5:1.

71. The sensor of claim 68 wherein gaps between the first and second pluralities of electrode teeth have an aspect ratio of at least 10:1.

72. A method of fabricating a gyroscopic sensor, comprising:

forming an insulative layer on a first substrate;

forming a recess in a first surface of a second substrate;

bonding the first surface of the second substrate to the first substrate so that the recess defines an enclosed cavity between the first and second substrates;

forming circuitry for the gyroscopic sensor on a second surface of the second substrate

etching a plurality of trenches in the second substrate from the second surface to the cavity, the plurality of trenches defining a vibratory structure connected to the first substrate.

73. The method of claim 72 wherein the vibratory structure has a thickness of at least 25 microns.

74. The method of claim 72 wherein the recess has a depth of about 1 micron.

75. The method of claim 72 wherein the etching step comprises a deep reactive ion etch.

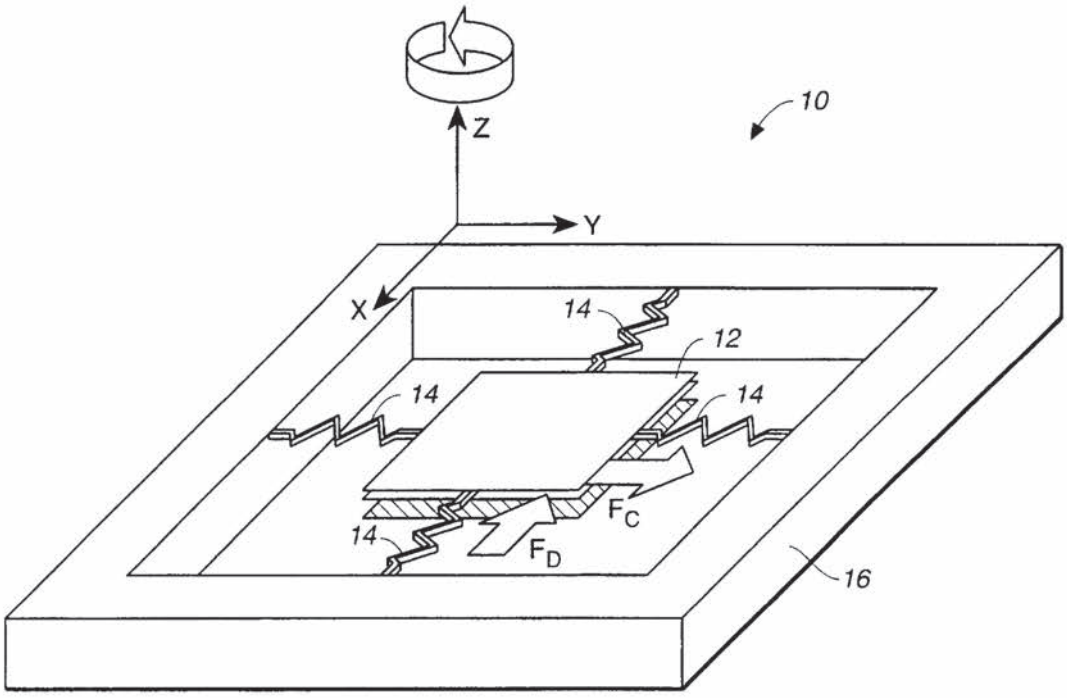


FIG._1

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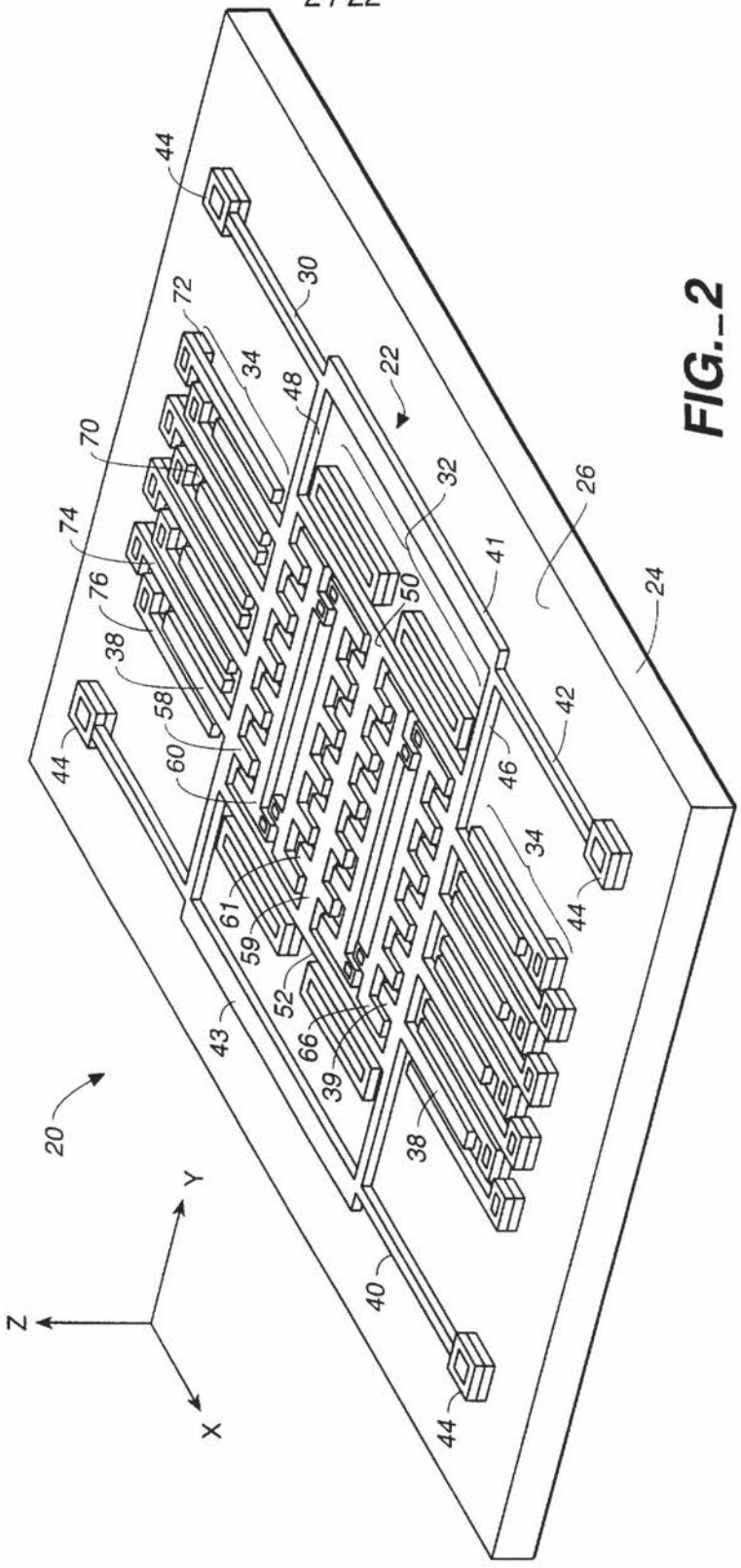


FIG._2

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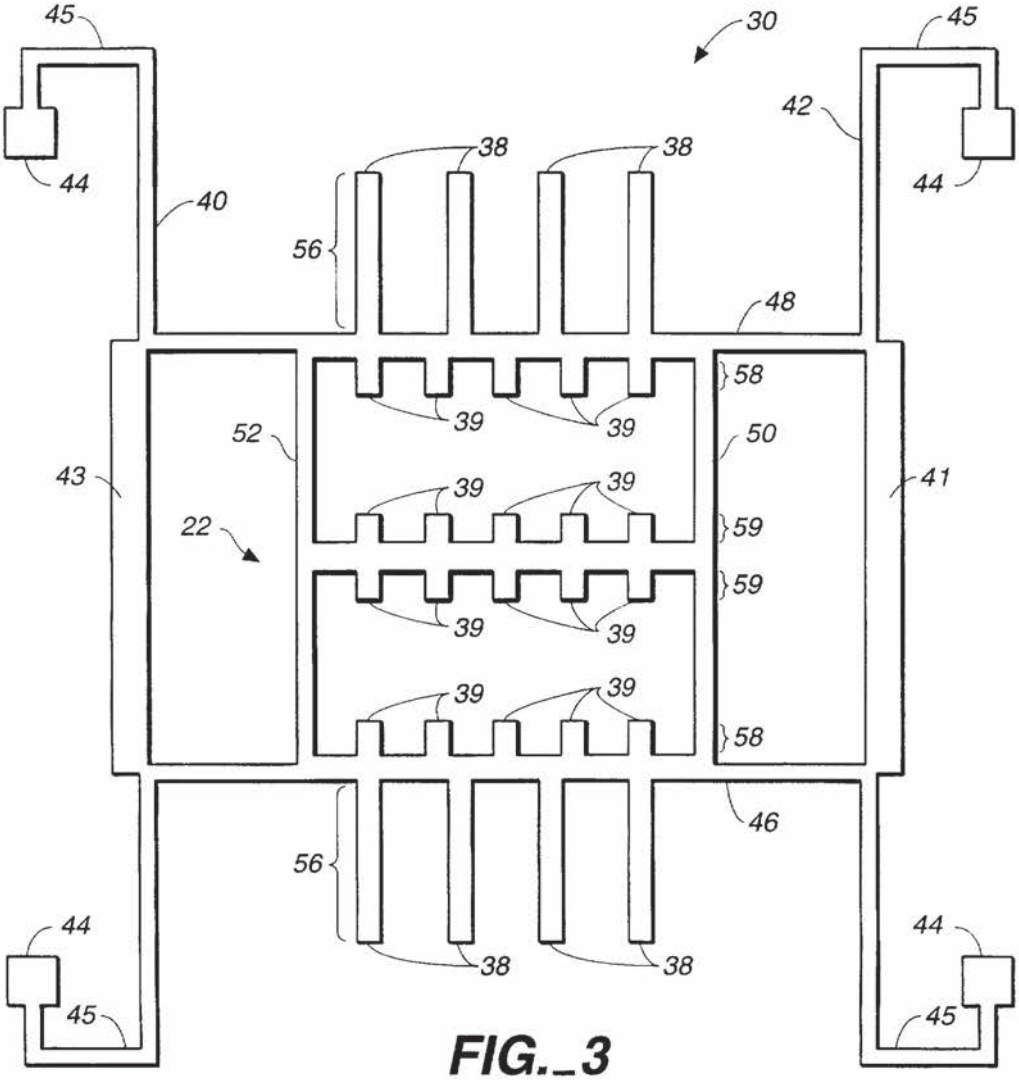


FIG._3

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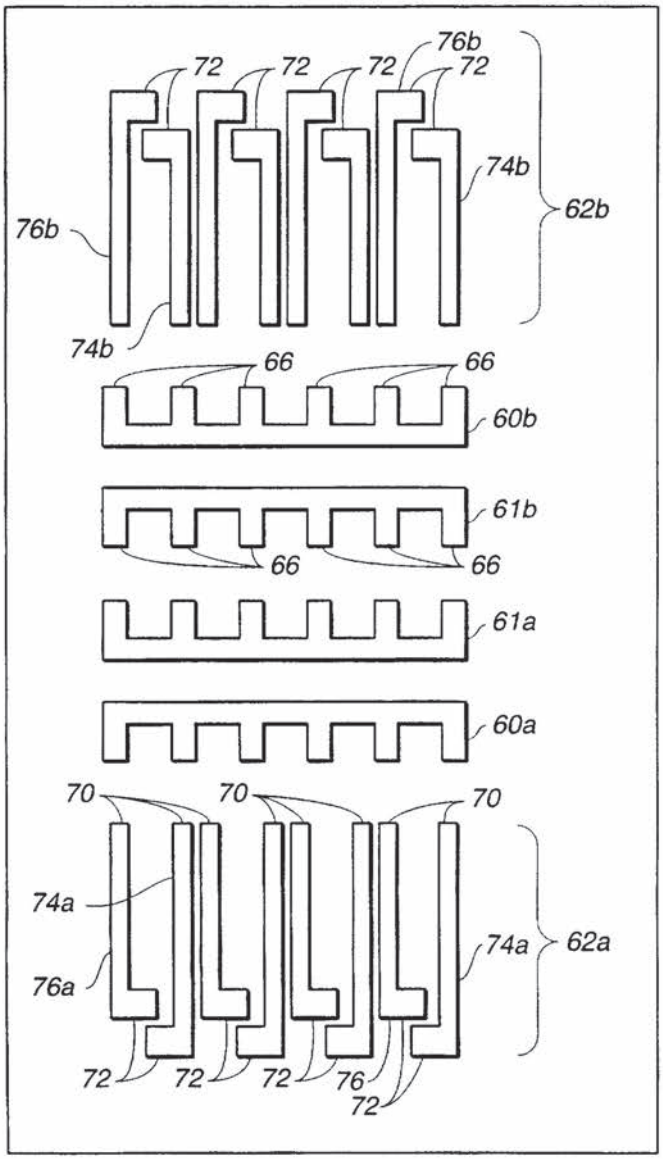


FIG._4

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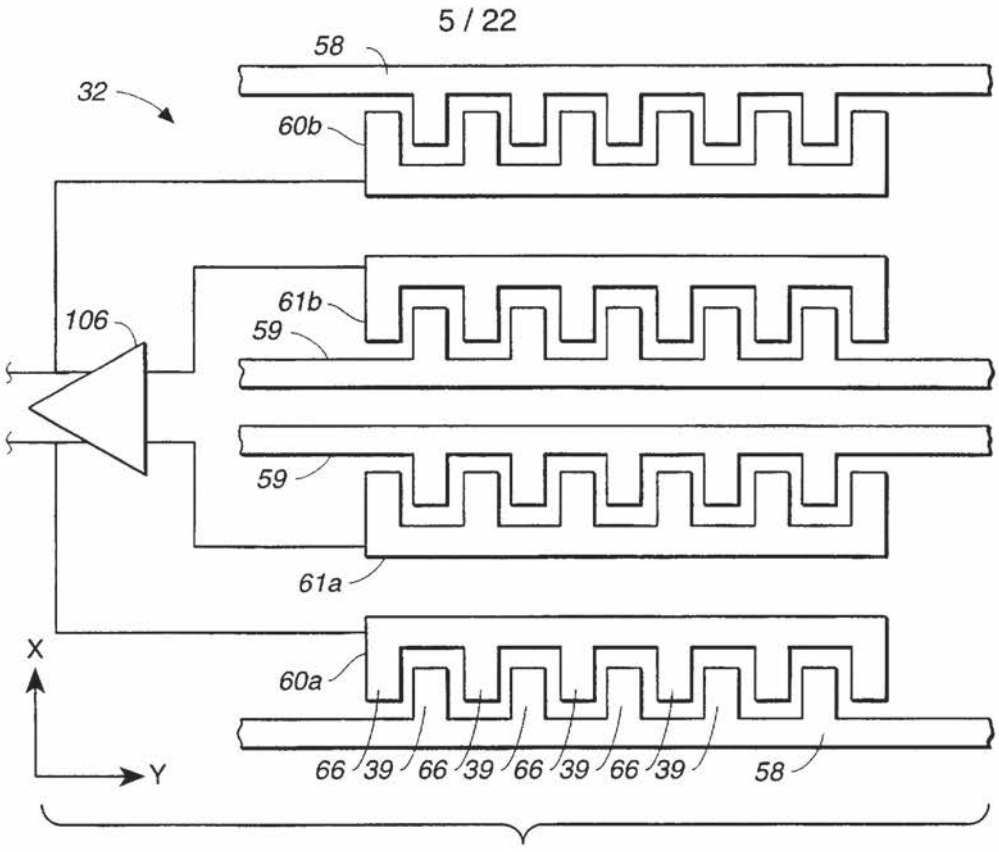


FIG._5

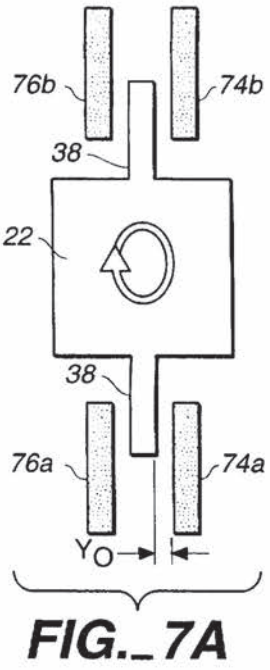


FIG._7A

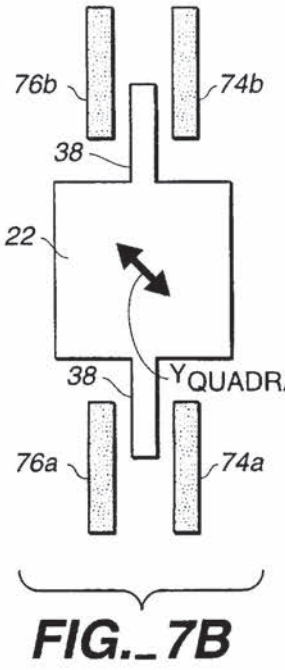


FIG._7B

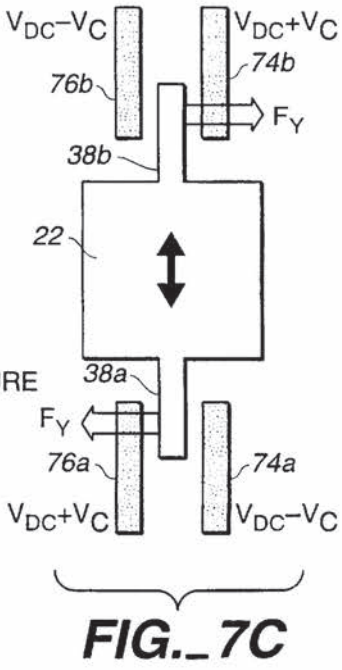


FIG._7C

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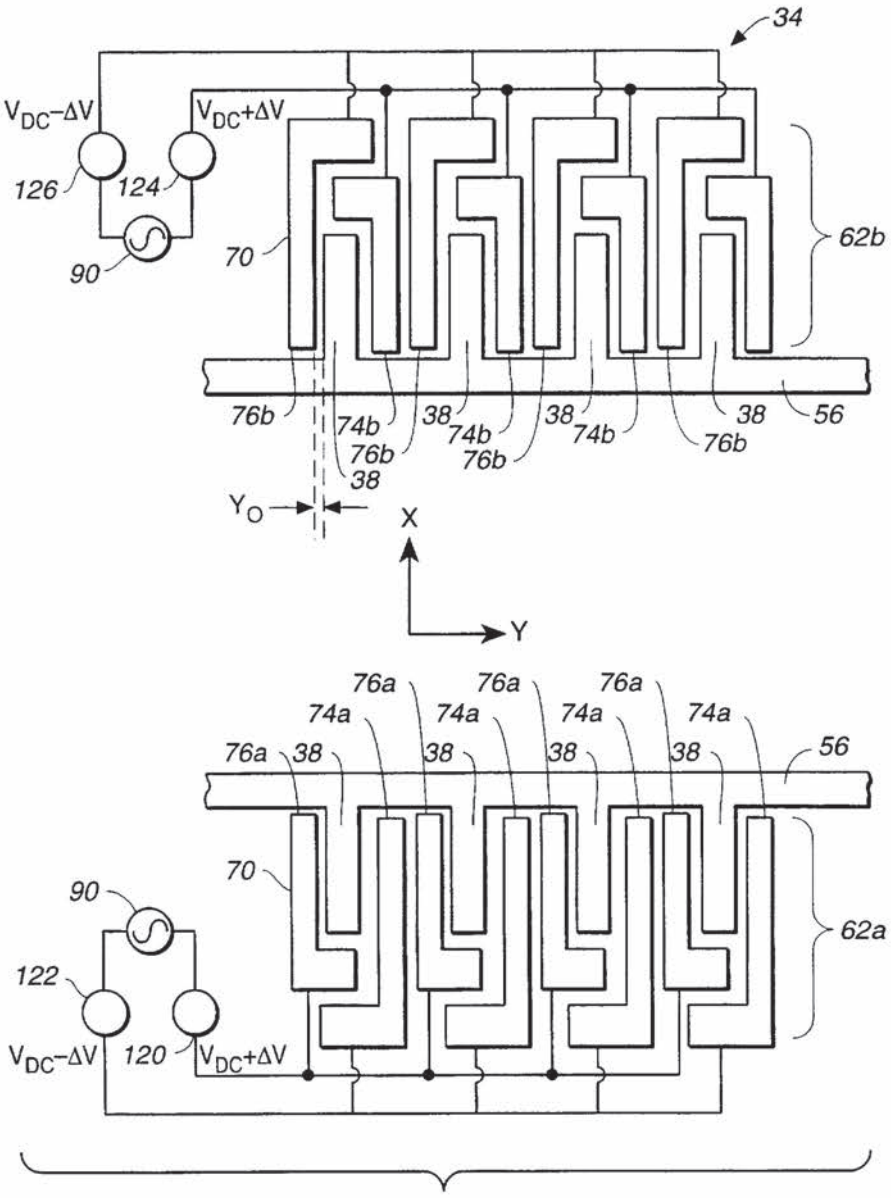


FIG._6

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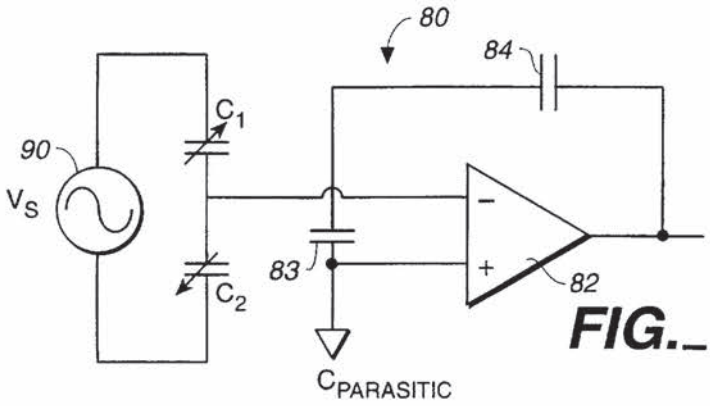


FIG._8A

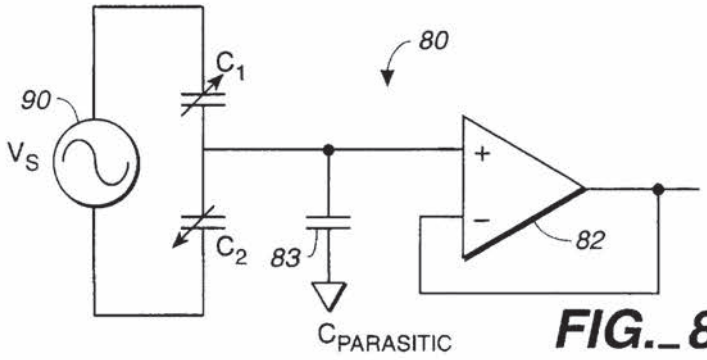


FIG._8B

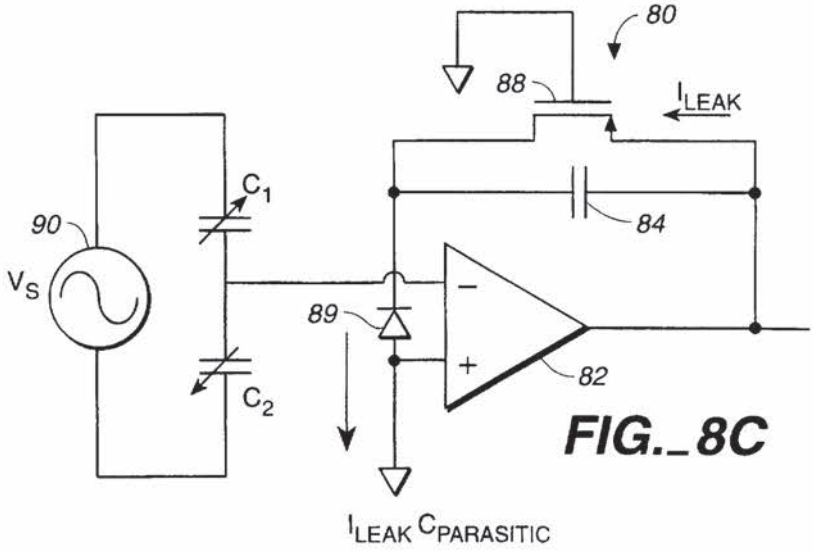


FIG._8C

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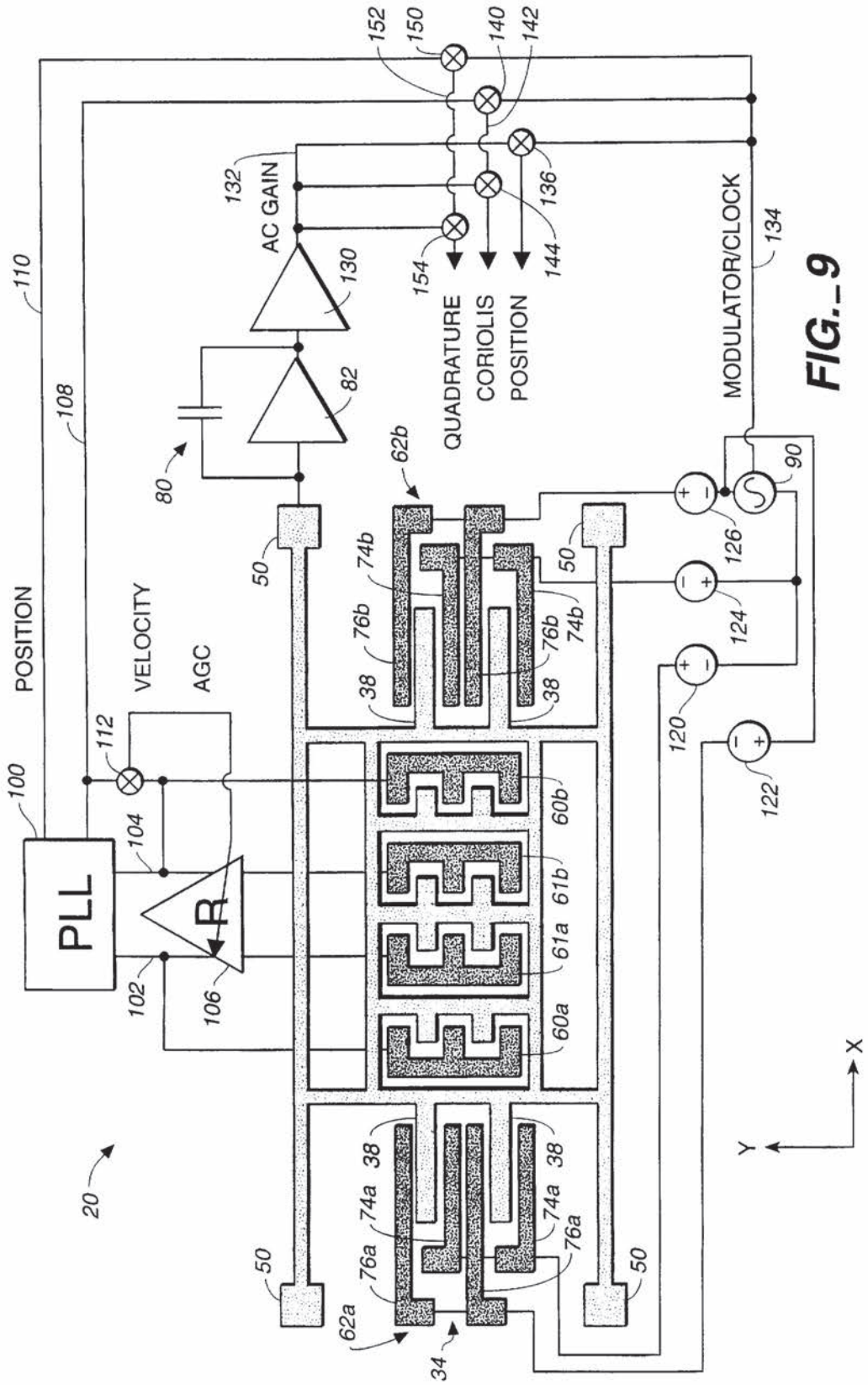


FIG._9

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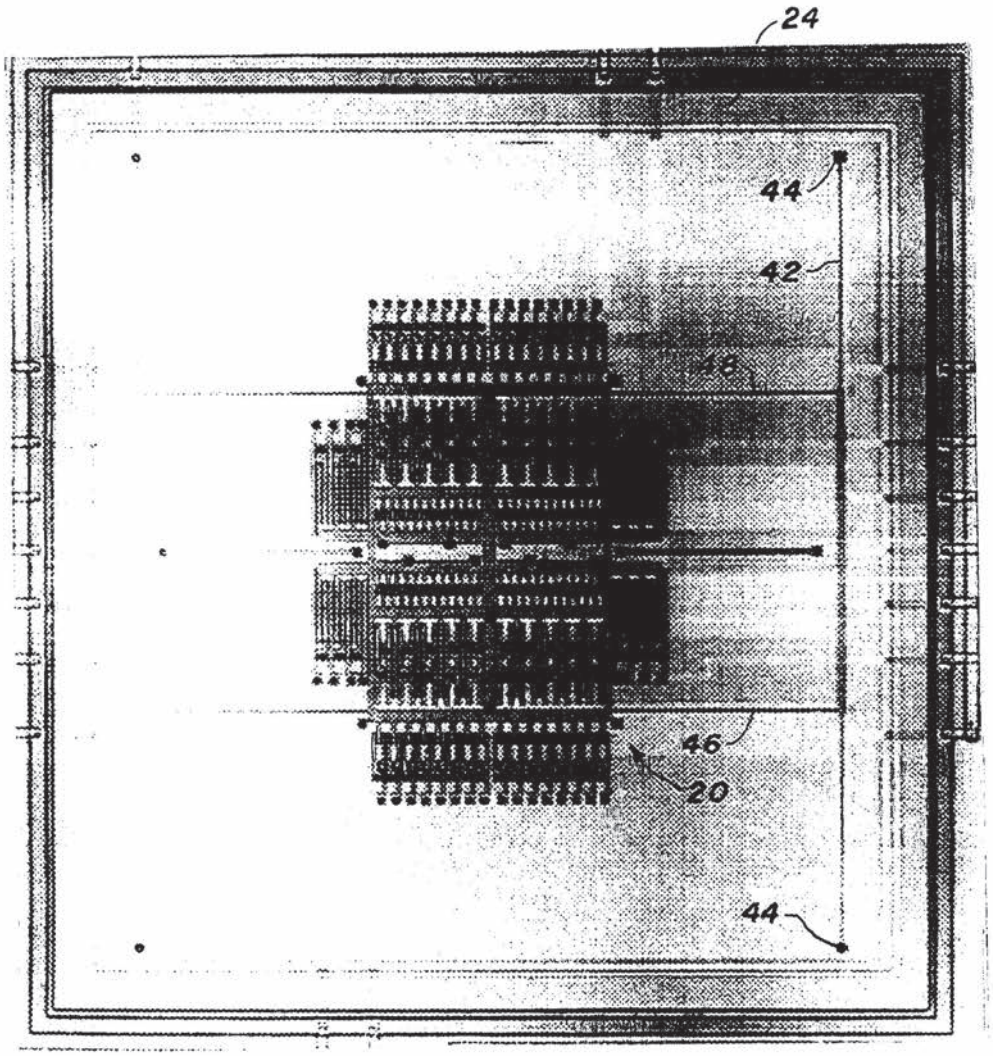


FIG._10

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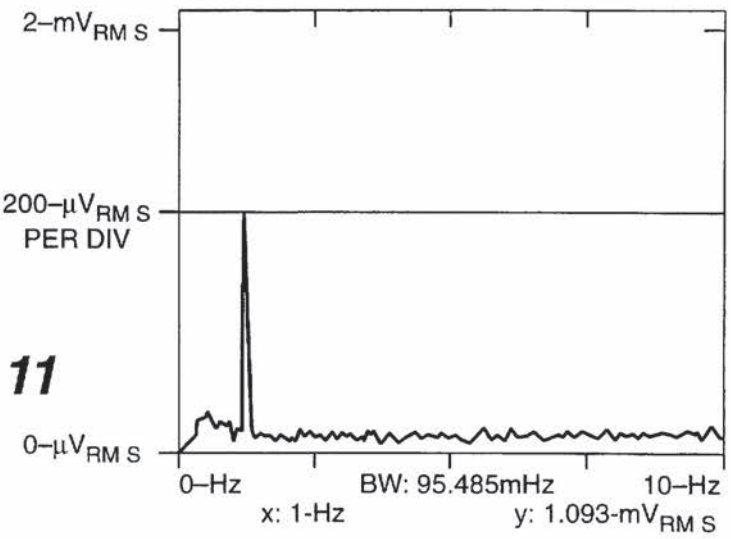


FIG._11

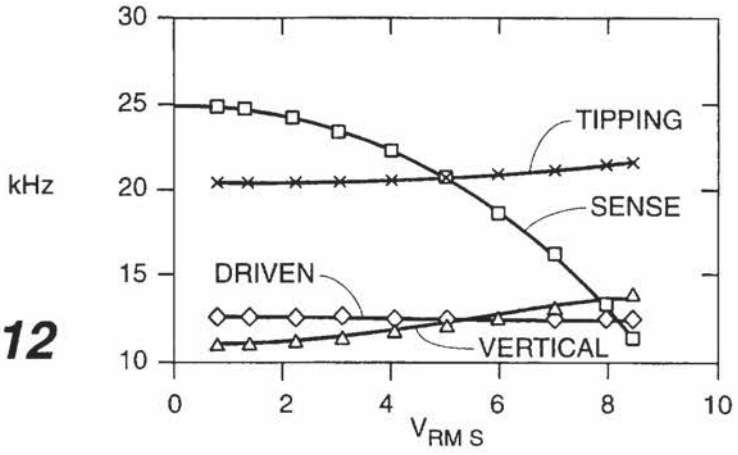


FIG._12

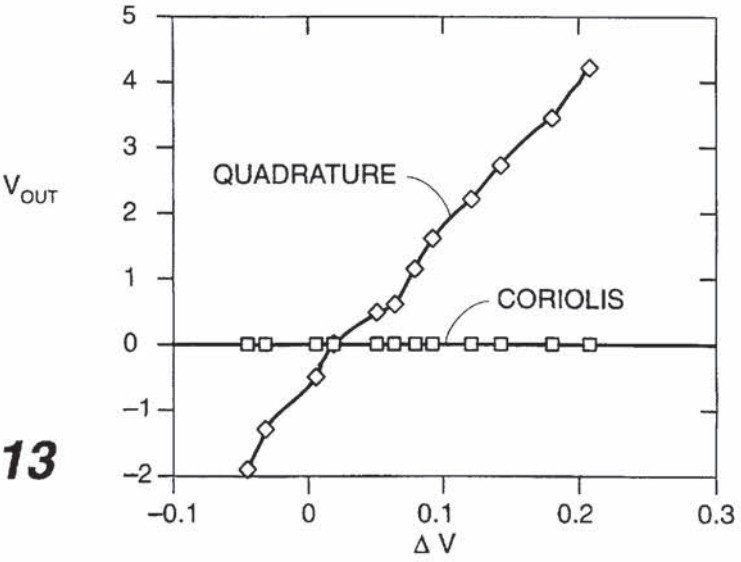


FIG._13

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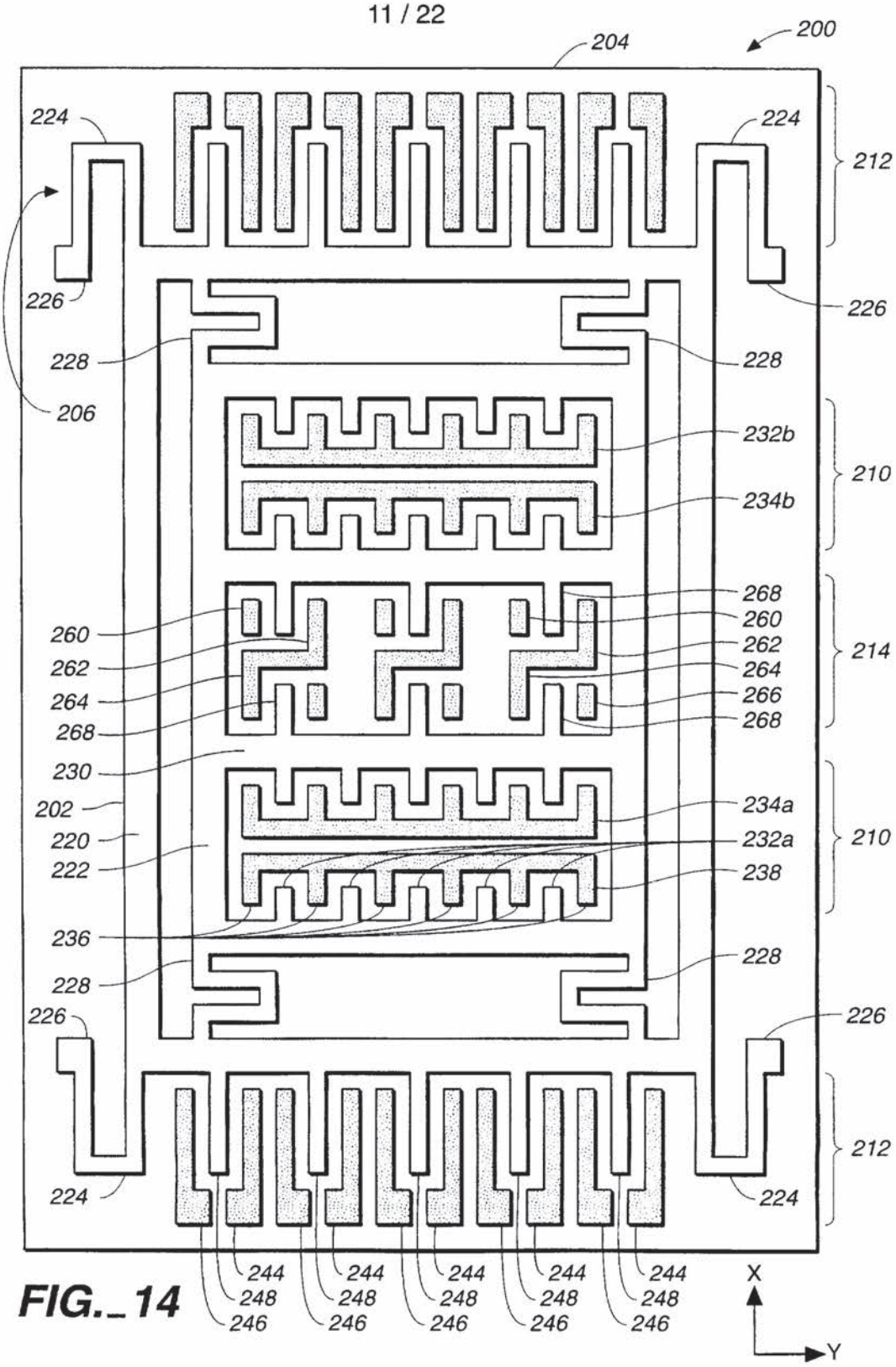
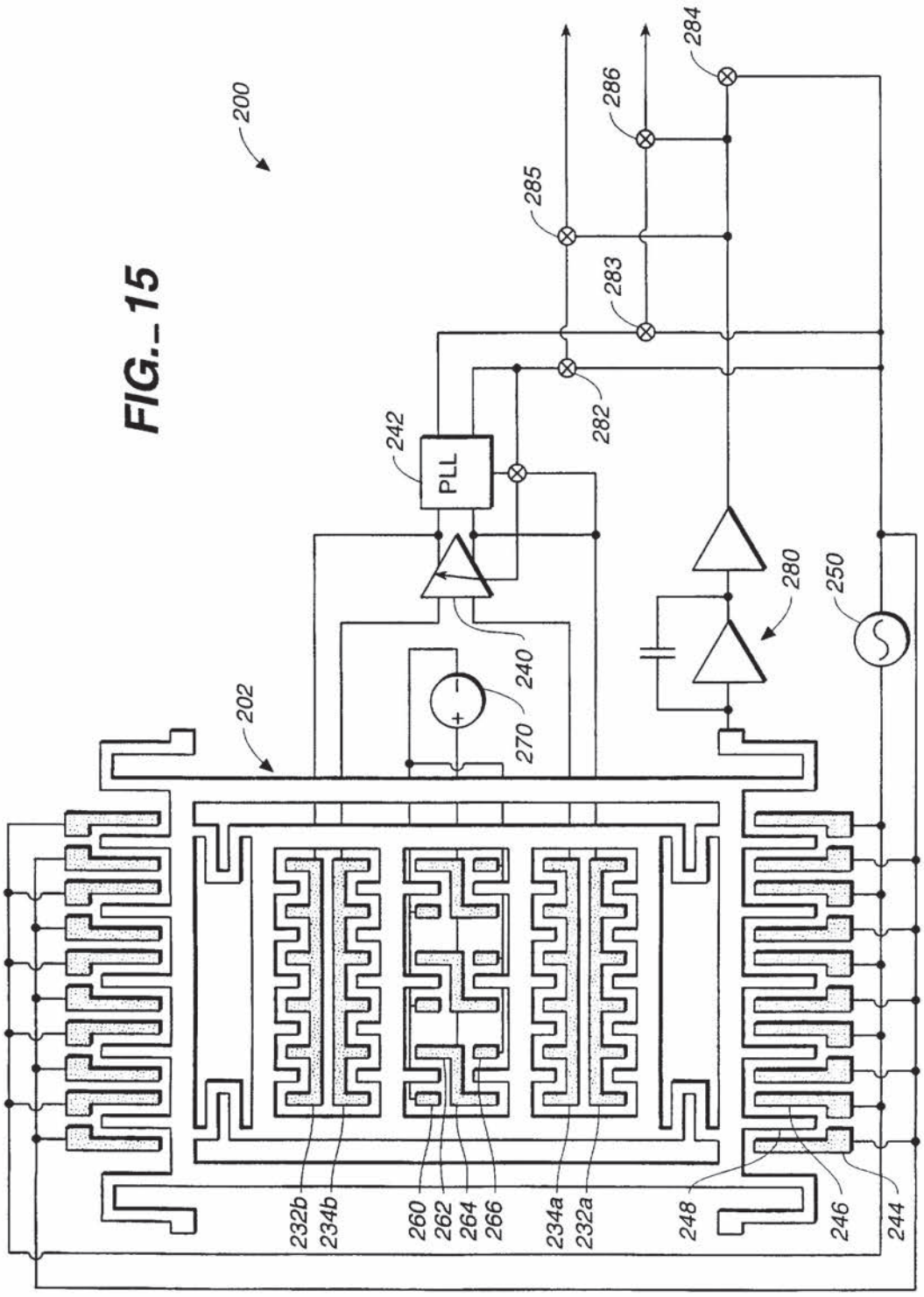


FIG._14

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FIG._15



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FIG._16

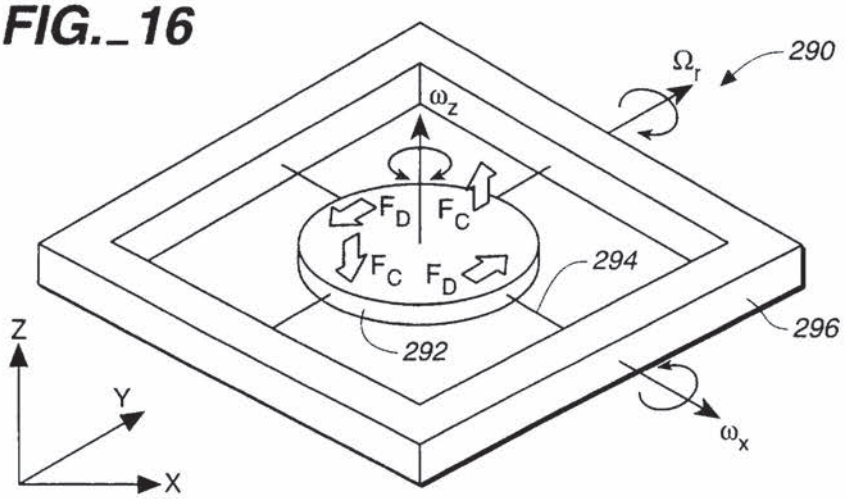
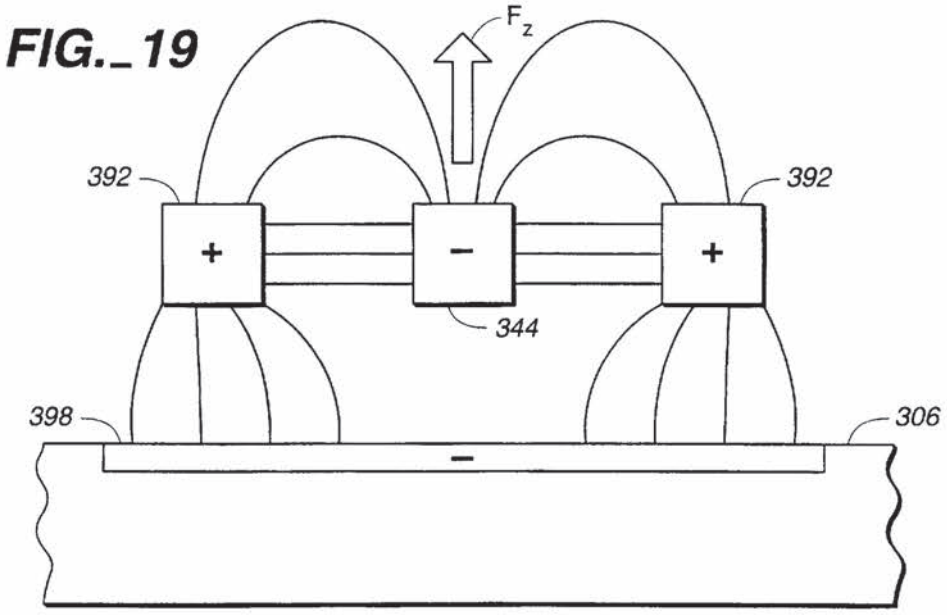
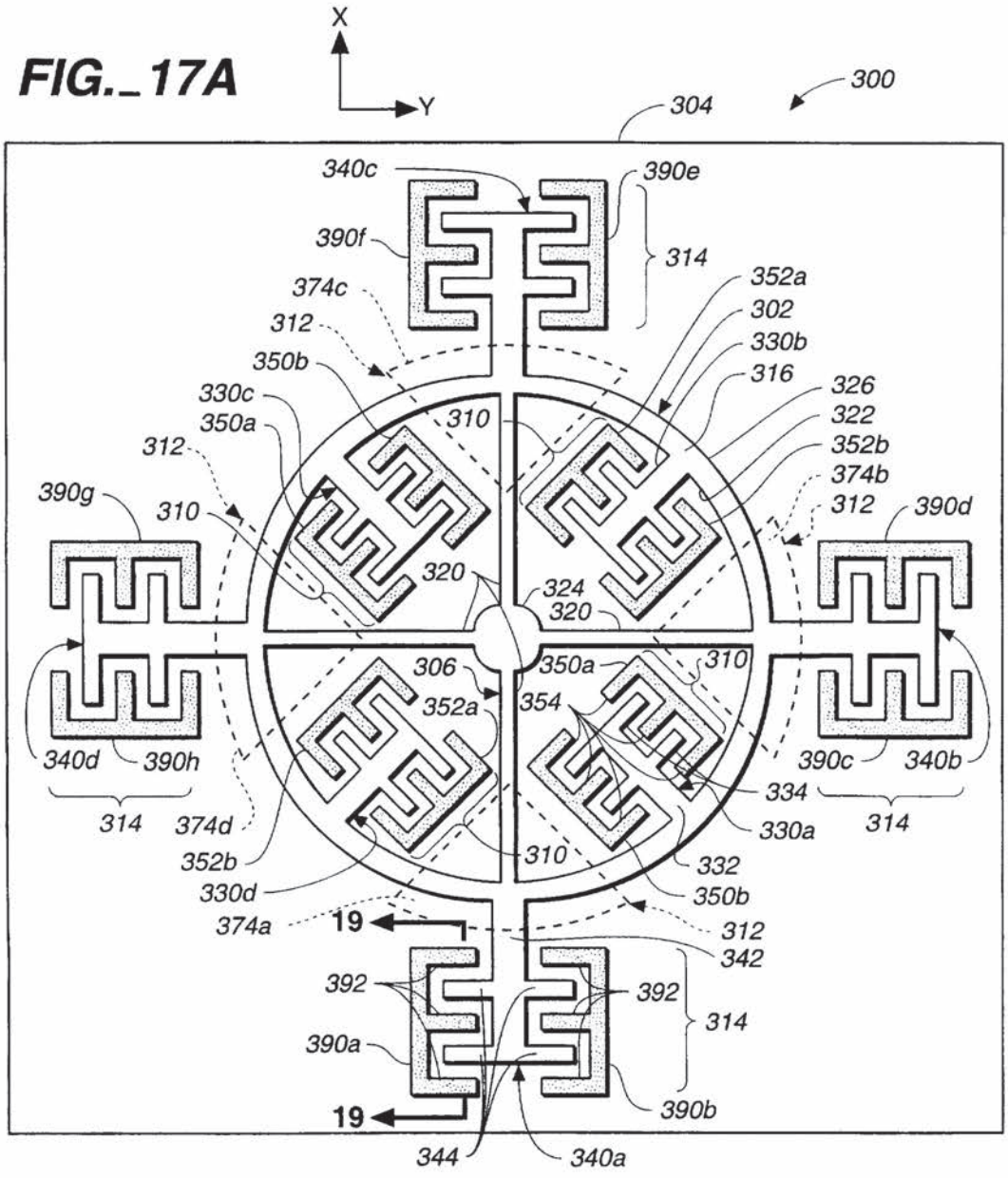


FIG._19



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FIG._17A



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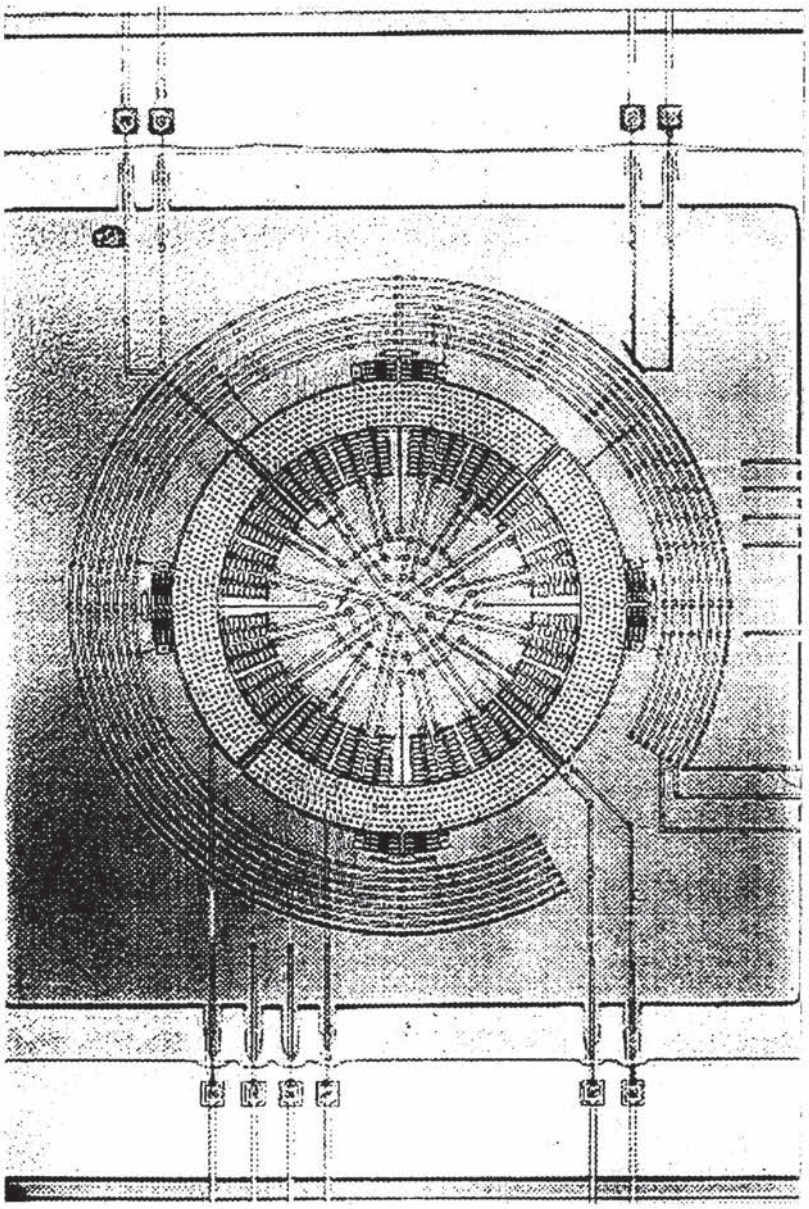
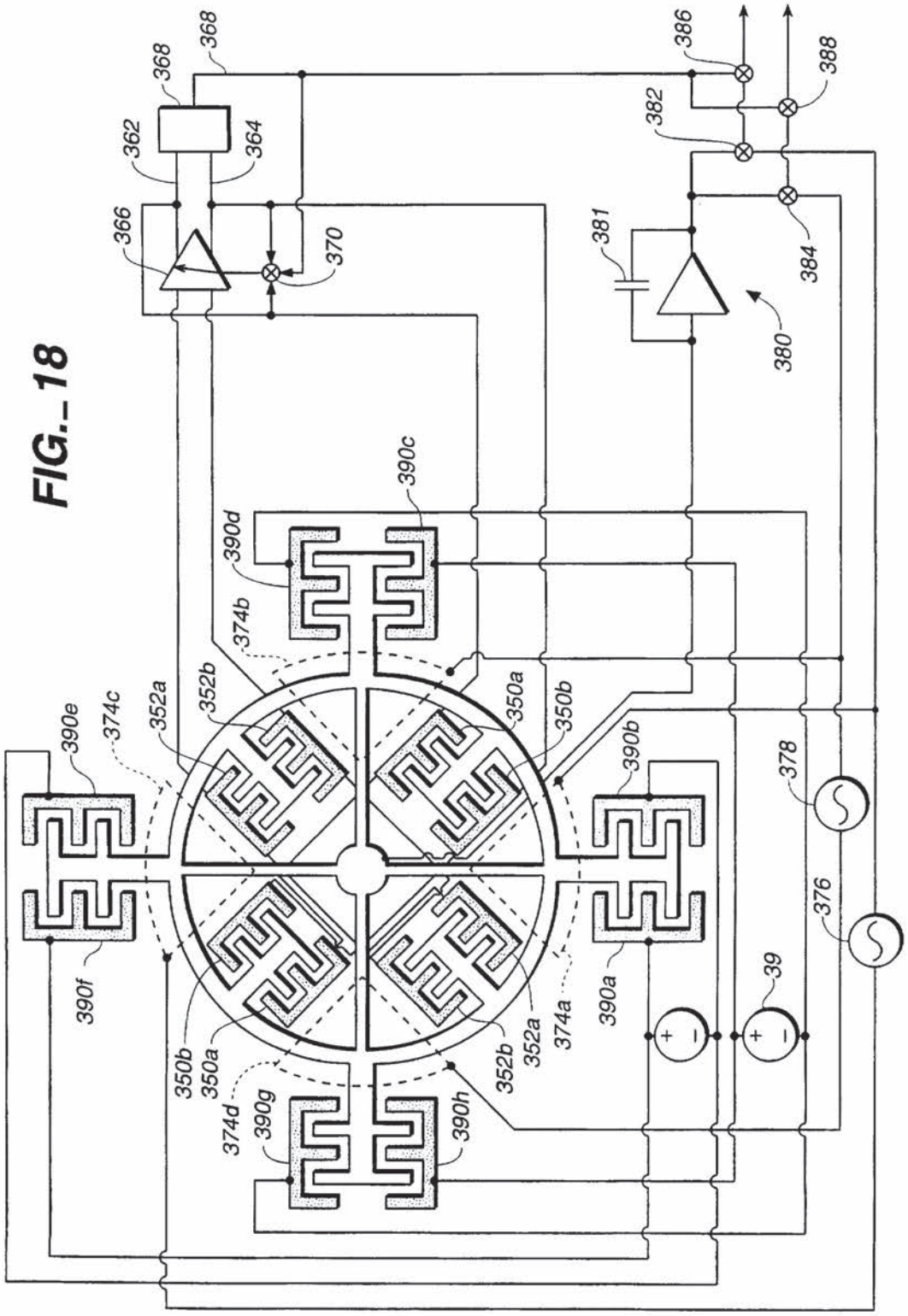


FIG._17B

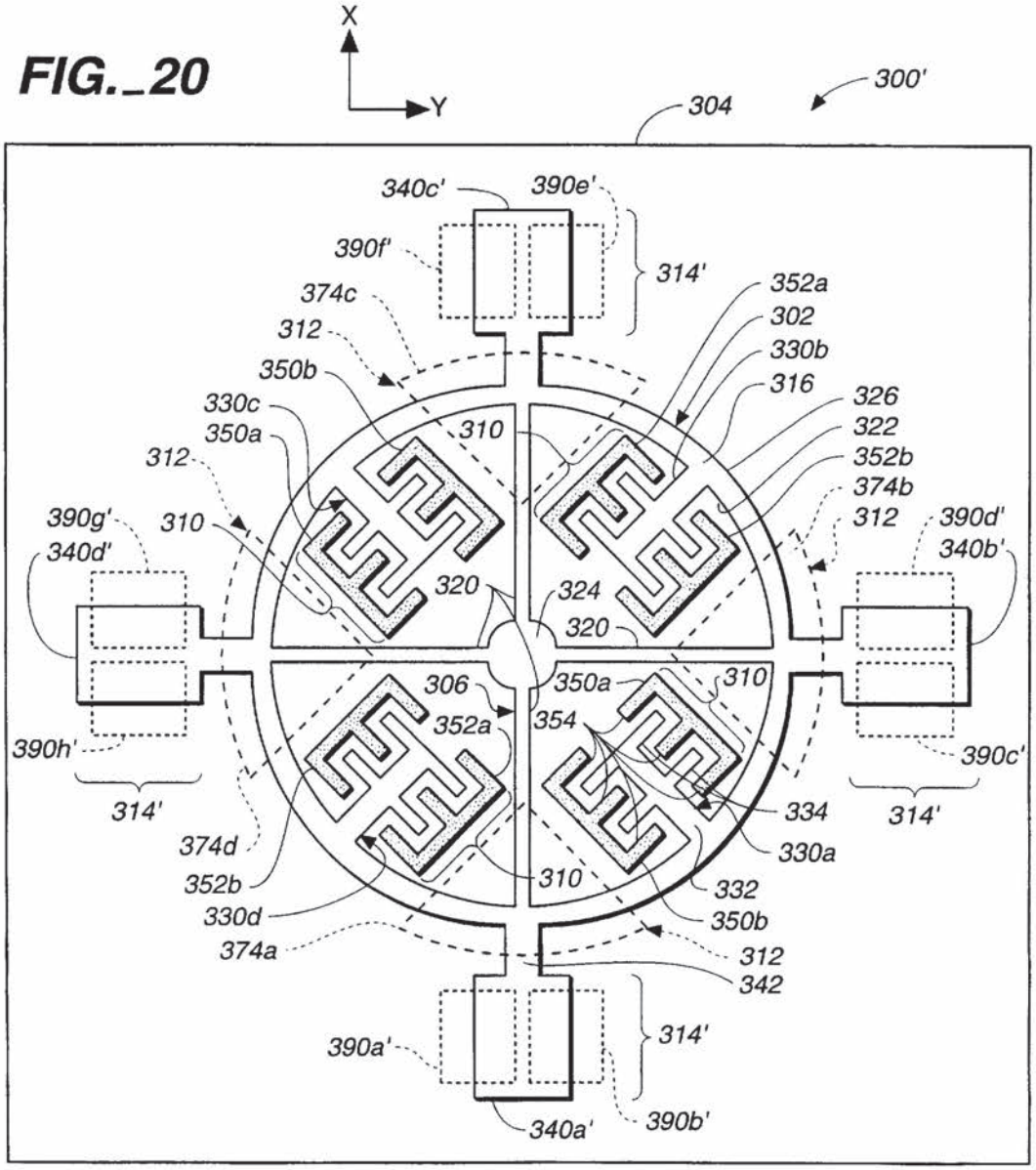
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FIG._18



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FIG._20



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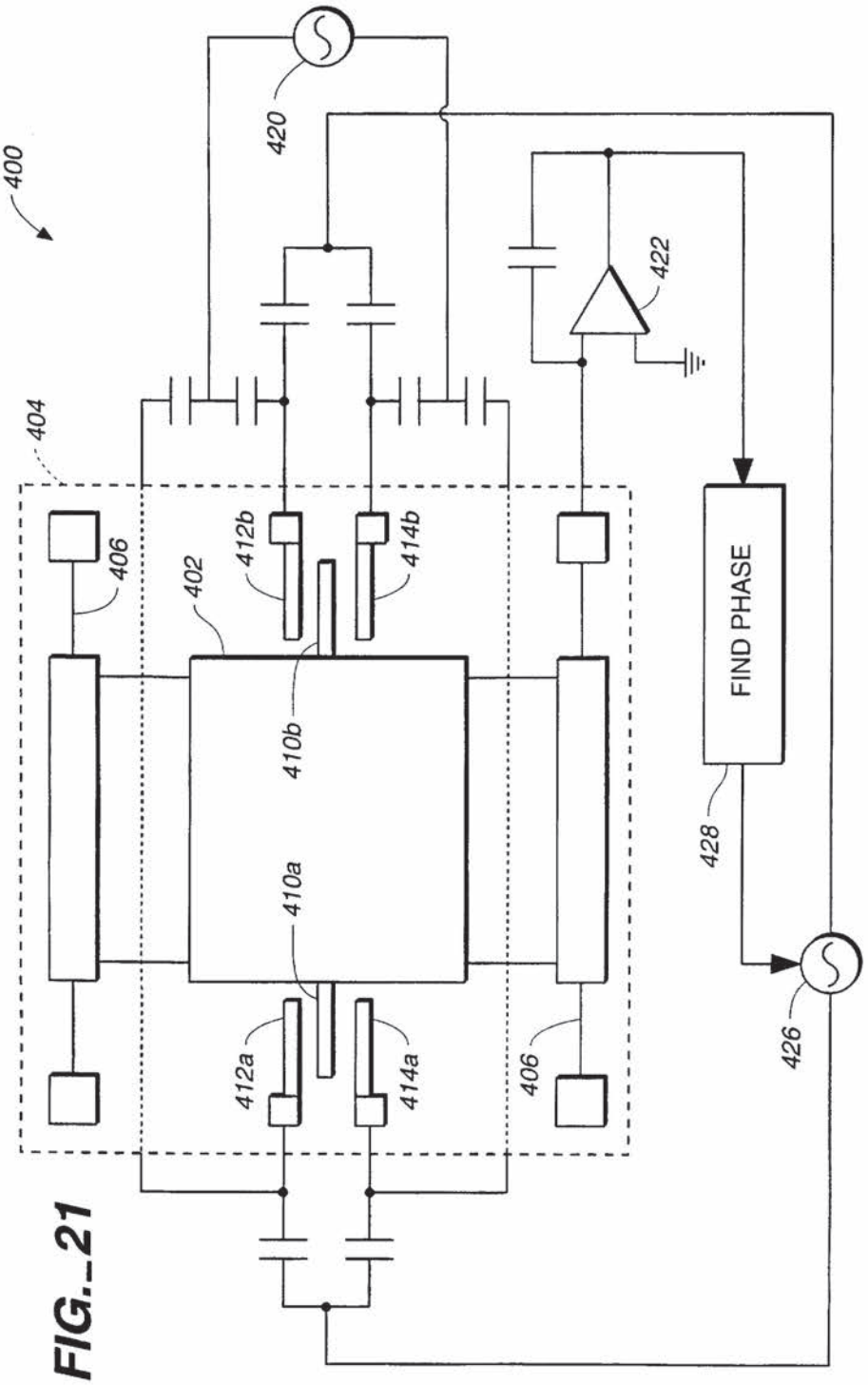


FIG._21

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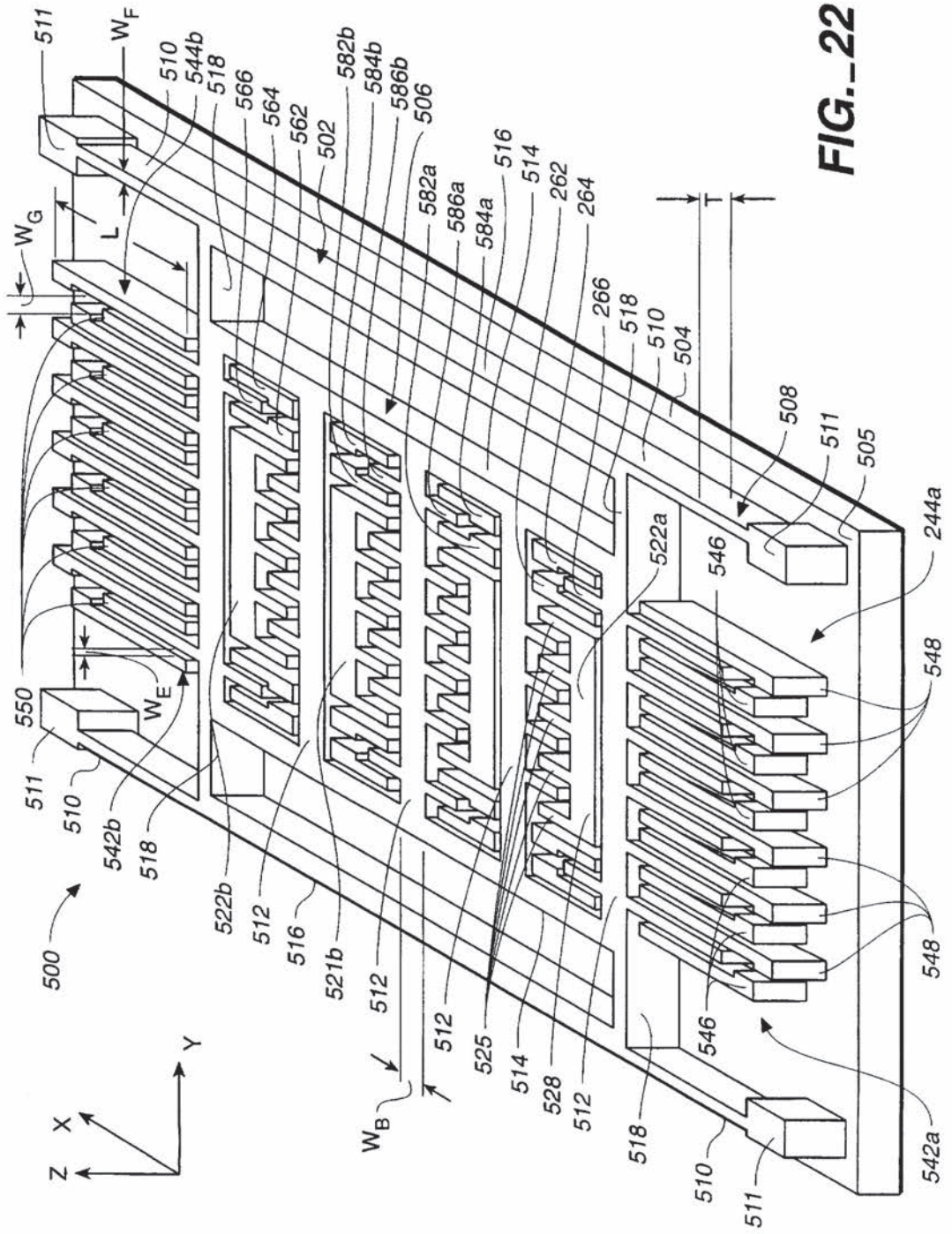


FIG._22

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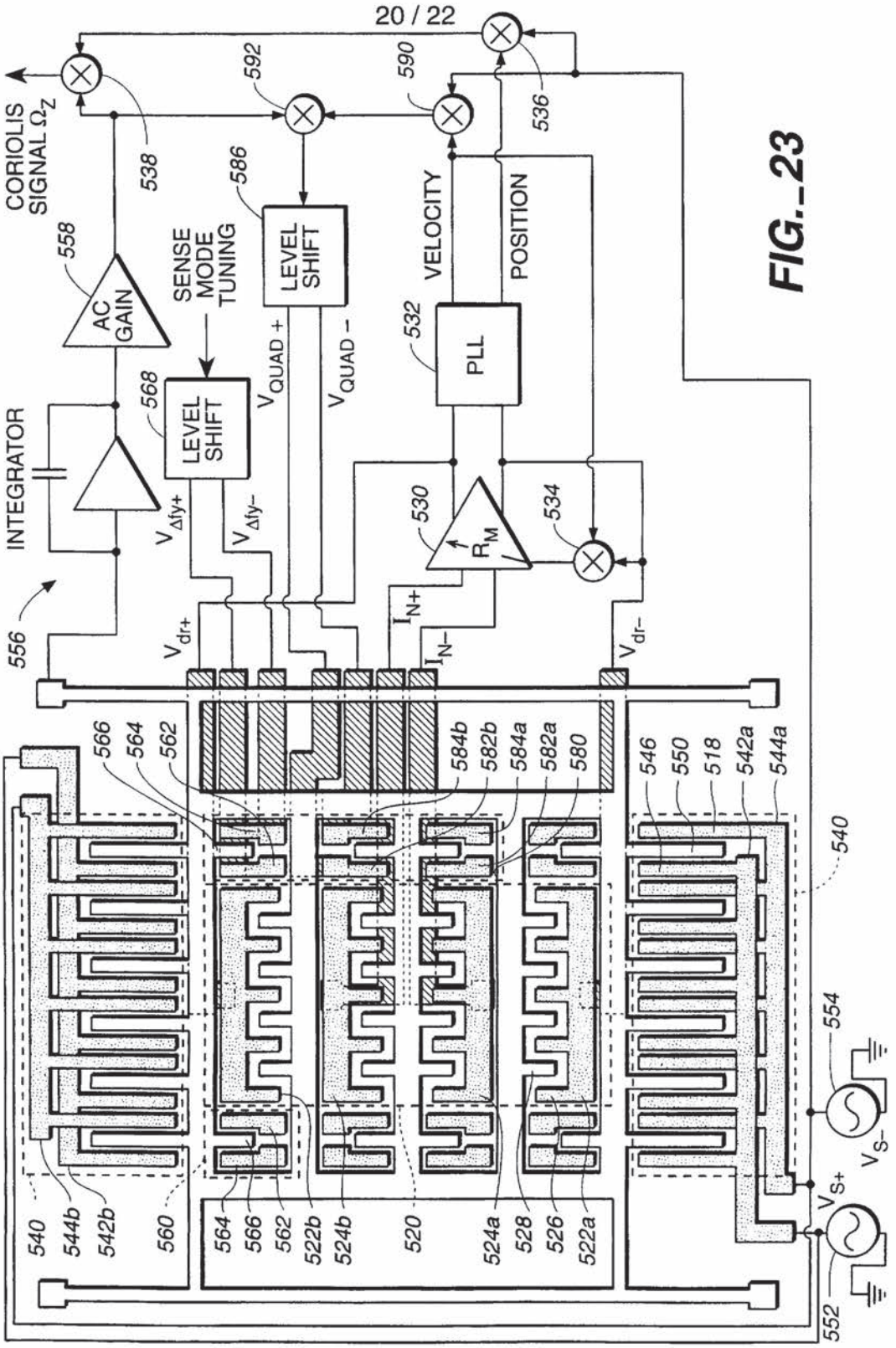


FIG._23

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FIG._24A

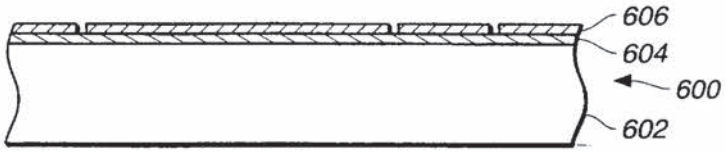


FIG._24B

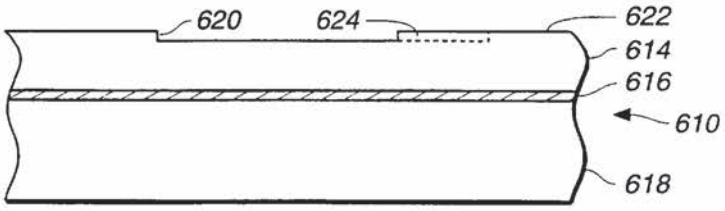


FIG._24C

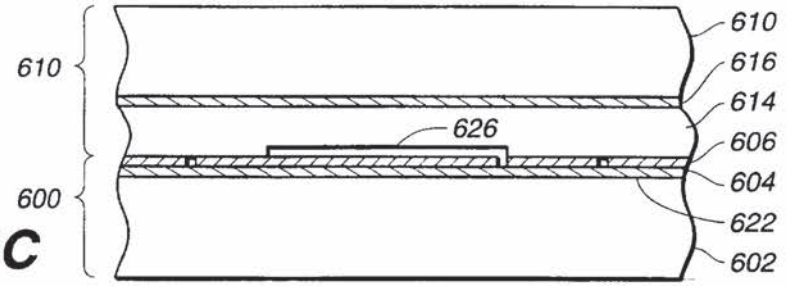


FIG._24D

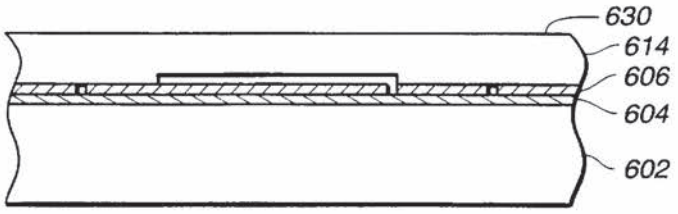
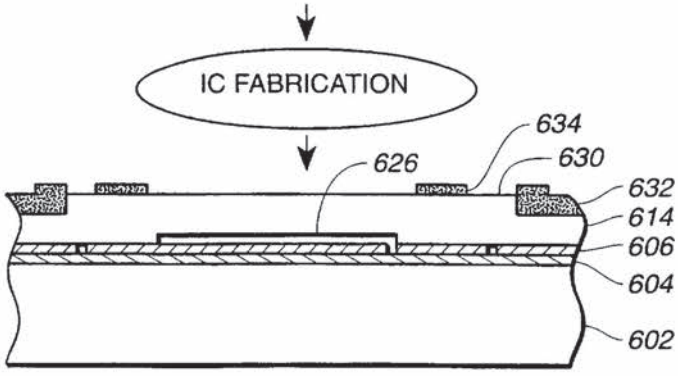


FIG._24E



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FIG._24F

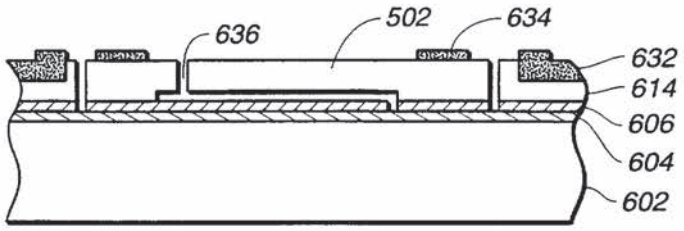
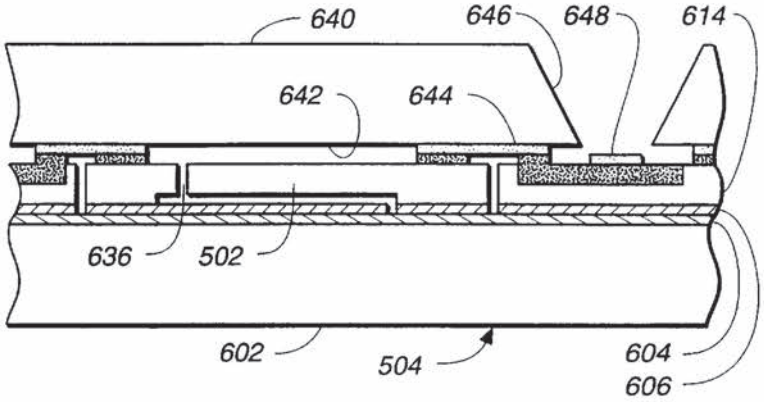


FIG._24G



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EXHIBIT 1057B

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(71) Applicant: THE REGENTS OF THE UNIVERSITY OF CALIFORNIA [US/US]; 21st floor, 300 Lakeside Drive, Oakland, CA 94612 (US).

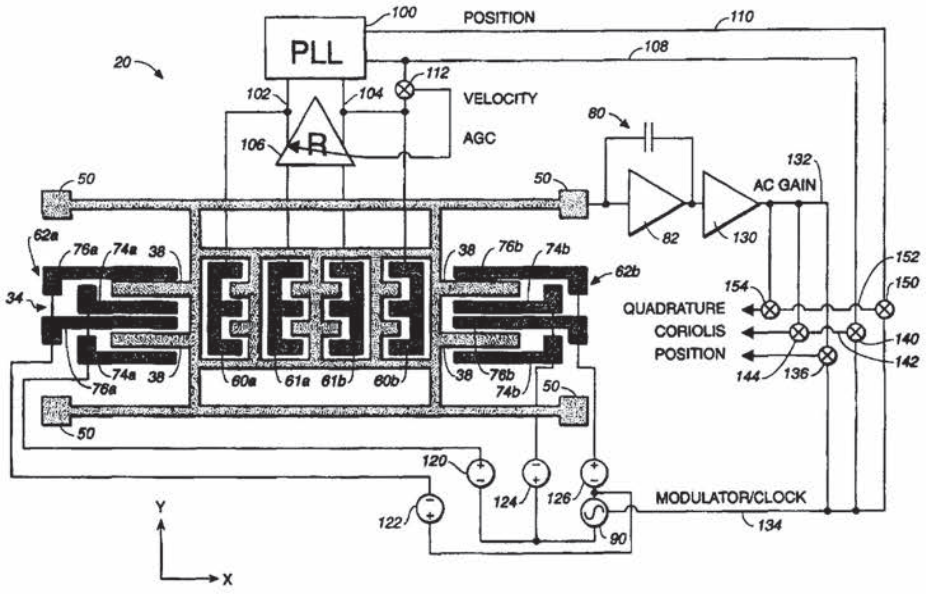
(72) Inventors: CLARK, William, A.; 35617 Pond Drive, Fremont, CA 94526 (US). JUNEAU, Thor; 1812 Delaware Street #201, Berkeley, CA 94709 (US). HOWE, Roger, T.; 3139 Sweetbriar Circle, Lafayette, CA 94549 (US).

(74) Agents: EGAN, William, J., III et al.; Fish & Richardson P.C., Suite 100, 2200 Sand Hill Road, Menlo Park, CA 94025 (US).

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(57) Abstract

A microfabricated gyroscope to measure rotation about an axis parallel to the surface of the substrate. A voltage differential may be applied between pairs of electrode fingers to reduce the quadrature error. A microfabricated gyroscope includes a vibratory structure and interdigited electrodes having a high aspect ratio.

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MICROMACHINED VIBRATORY RATE GYROSCOPE

Background of the Invention

The present invention relates generally to microfabricated sensors, and more particularly to microfabricated gyroscopic sensors.

Multi-axis sensors are highly desirable for inertial sensing of motion in three dimensions. Previously, such sensors were constructed of relatively large and expensive electromagnetic devices. More recently, micromechanical sensors have been fabricated using semiconductor processing techniques. Specifically, micromechanical accelerometers and gyroscopes have been formed from silicon wafers by using photolithographic techniques. Such microfabricated sensors hold the promise of large scale production and therefore low cost.

One objective in the construction of microfabricated sensors is to increase the sensitivity and improve the signal to noise ratio of the device. Another objective is to simplify the fabrication steps so as to reduce the cost and complexity and to increase the yield in the manufacturing process.

The integration of three gyroscopic sensors to measure the rotation rates about the three separate axes coupled with three accelerometric sensors to measure the acceleration along the three axes on a single chip would provide a monolithic, six degree-of-freedom inertial measurement system capable of measuring all possible translations and orientations of the chip.

It would be useful to provide a gyroscopic sensor to measure rotation about axes parallel to the surface of

a substrate on which the gyroscopic sensor was fabricated. It would also be useful to provide a gyroscopic sensor with reduced noise.

Summary of the Invention

In one aspect, the invention is directed to a gyroscopic sensor including a substrate, a mass connected to the substrate by a suspension system, a drive system to cause the mass to vibrate along a drive axis substantially parallel to a surface of the substrate, and a position sensor to measure a deflection of the mass along a sense axis substantially parallel to the surface of the substrate. Rotation of the mass about an axis of rotation substantially perpendicular to the surface of the substrate and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along the sense axis.

Implementations of the invention include the following. A processor may be coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the axis of rotation. The gyroscopic sensor may include a first sense electrode projecting from the mass, a second sense electrode connected to the substrate and positioned on a first side of the first electrode, and a third sense electrode connected to the substrate and positioned on an opposing second side of the first electrode. The position sensor may sense a change in capacitance between the first electrode and the second and third electrodes. The first, second and third electrodes may be substantially coplanar and each electrode has a longitudinal axis substantially aligned with the drive axis. The drive system may include a first drive electrode projecting

from the mass, a second drive electrode connected to the substrate and positioned on a first side of the first electrode, and a third drive electrode connected to the substrate and positioned on an opposing second side of the first electrode. An alternating voltage may be applied between the between the first electrode and the second and third electrodes. A voltage source may apply a voltage between a plurality of correction electrodes connected to the substrate to cause the mass to vibrate, absent the Coriolis force, more precisely along the drive axis. A voltage source may apply a voltage between a first tuning electrode connected to the substrate and a second tuning electrode connected to the mass to adjust a resonant frequency of vibrations of the mass along the sense axis.

In another aspect, the invention is directed to a method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system. The mass is rotated about an axis of rotation and the mass is caused to vibrate substantially along a drive axis. Rotation of the mass about the axis of rotation and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along a sense axis. A deflection of the mass along the sense axis is measured, and a voltage is applied between electrode fingers connected to the substrate to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

In another aspect, the present invention is directed to a microfabricated structure. The structure comprises a substrate, a mass connected to the substrate by a suspension system to vibrate in a plane parallel to a surface of the substrate, and three pluralities of

electrode fingers. The first plurality of electrode fingers projects from the mass along a first axis in the plane. The second and third plurality of electrode fingers, electrically isolated from each other, are coplanar with the first plurality of electrode fingers, are connected to the substrate and project substantially along the first axis. The first, second and third plurality of electrode fingers are interdigitated such that each of the first plurality of electrode fingers is adjacent to one of the second plurality of electrode fingers and one of the third plurality of electrode fingers.

Implementations include the following features. A voltage source may apply a voltage between the second and third plurality of electrode fingers. The structure may further comprise a fourth plurality of electrode fingers, coplanar with the first, second and third plurality of electrode fingers, projecting from the mass along the first axis, and a fifth plurality of electrode fingers connected to the substrate but electrically isolated from the second and third plurality of electrode fingers, the fourth and fifth plurality of electrode fingers being interdigitated. Each of the first plurality of electrode fingers may be longer than each of the fourth plurality of electrode fingers.

In another aspect, the invention is directed to a microfabricated structure. The structure comprises a substrate and a suspension system to permit a mass to vibrate in a plane parallel to a surface of the substrate. The suspension system includes first and second substantially parallel beams, each of the first and second beams anchored at both ends to the substrate, and third and fourth substantially parallel beams, one

end of each of the third and fourth beams connected to the first beam and another end connected to the second beam.

Implementations include the following features. The structure may include a plurality of fingers projecting along an axis substantially parallel to the first and second beams. The structure may comprise a fifth and a sixth beam one end of each of the fifth beam and sixth beams connected to the third beam and another end connected to the fourth beam, and a seventh beam, one end of the seventh beam connected to the fifth beam and another end connected to the sixth beam. The structure may further comprise a plurality of fingers projecting from the seventh beam along an axis substantially parallel to the first and second beams. Sections of the first and second beams located between the third and fourth beams may be substantially rigid to prevent rotation of the mass.

In another aspect, the invention is directed to a sensor. The sensor comprises a substrate, a mass connected to the substrate by a suspension system to vibrate in a plane parallel to a surface of the substrate, and three pluralities of electrode fingers. The first plurality of electrode fingers projects from the mass along a first axis in the plane. The second and third plurality of electrode fingers, are connected to the substrate and project substantially along the first axis. the first, second and third plurality of electrode fingers are interdigitated such that each of the first plurality of electrode fingers is adjacent to one of the second plurality of electrode fingers and one of the third plurality of electrode fingers. A voltage source applies a first DC voltage between the second and third

plurality of electrode fingers to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

Implementations may include the following features. A set of electrode fingers may be positioned opposing the three pluralities of electrode fingers, and a second voltage source for may apply a second DC voltage between a fifth and sixth plurality of electrode fingers to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis. The second DC voltage may be substantially equal in magnitude but opposite in sign to the first DC voltage. The first plurality of electrode fingers may be electrically coupled to the second plurality of electrode fingers. The sensor may include a voltage source for applying a third DC voltage between the first and third pluralities of electrode fingers and the second, third, fifth and sixth pluralities of electrode fingers to adjust the resonant frequency of vibrations of the mass along a second axis in the plane perpendicular to the first axis.

In another aspect, the invention is directed to a sensor. The sensor comprises a substrate, a mass connected to the substrate by a suspension system to vibrate in a plane parallel to a surface of the substrate, and three pluralities of electrode fingers. The first plurality of electrode fingers projects from the mass along a first axis in the plane. The second and third plurality of electrode fingers, are connected to the substrate and project substantially along the first axis. the first, second and third plurality of electrode fingers are interdigitated such that each of the first plurality of electrode fingers is adjacent to one of the second plurality of electrode fingers and one of the

third plurality of electrode fingers. A voltage source applies a DC voltage between the first plurality of electrode fingers and the second and third plurality of electrode fingers to adjust the resonant frequency of vibrations of the mass along a second axis in the plane perpendicular to the first axis.

In another aspect, the invention is directed to a gyroscope for sensing rotation about a Z-axis. The gyroscope comprises a substrate, a mass connected to the substrate by a suspension system to vibrate in a plane parallel to a surface of the substrate, a drive system to cause the mass to vibrate substantially along a first axis in the plane, and three pluralities of electrode fingers. The first plurality of electrode fingers projects from the mass along a first axis in the plane. The second and third plurality of electrode fingers, are connected to the substrate and project substantially along the first axis. The first, second and third plurality of electrode fingers are interdigitated such that each of the first plurality of electrode fingers is adjacent to one of the second plurality of electrode fingers and one of the third plurality of electrode fingers. A position sensor is coupled to the first plurality of electrode fingers for measuring the deflection of the mass along a second axis in the plane perpendicular to the first axis. Rotation of the mass about a Z-axis perpendicular to the surface and vibration of the mass along the first axis generates a coriolis force to deflect the mass along the second axis. A signal processor is coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the Z-axis.

Implementations include the following features. A voltage source may apply an AC voltage having a first frequency between the second and third plurality of electrode fingers. A voltage may be applied between the second and third pluralities of electrode fingers to form a capacitive bridge with the first plurality of electrodes, and the position sensor may be coupled to the first plurality of electrodes to detect changes in capacitance when the mass is deflected along the second axis. The sensor may includes an integrator to integrate a signal from the first plurality of electrode fingers. The drive system may generate a signal to cause the mass to oscillate along the first axis at a second frequency. The drive system may include a phase-locked loop to prevent phase-shifting of the signal. The sensor may include a first mixer to mix the signal from the drive system with a signal from the voltage source. The sensor may include a second mixer to mix a signal from the first mixer with an output signal from the position sensor to produce a position quadrature signal or coriolis signal. The sensor may include a mixer to mix an output signal from the position sensor with a signal from the voltage source to produce a position signal.

In another aspect, the invention is directed to a microfabricated gyroscopic sensor for measuring rotation about an input axis. The gyroscopic sensor includes a substrate, a mass, and a suspension system connecting the mass to the substrate. A drive system causes the mass to oscillate substantially about a drive axis, and a position sensor measures a rotation of the mass about a sense axis. Rotation of the mass about the input axis and oscillation of the mass about the drive axis generates a Coriolis force to oscillate the mass about

the sense axis. A voltage source to apply a voltage between a plurality of electrodes associated with the substrate to cause the mass to oscillate, in the absence of the Coriolis force, more precisely about the drive axis.

Implementations of the invention include the following. A processor may be coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the axis of rotation. A second voltage source may apply a second voltage between electrodes connected to the mass and the electrodes connected to the substrate to adjust a resonant frequency of oscillations of the mass about the sense axis. The drive axis may be substantially perpendicular to the surface of the substrate and the axis of rotation and sense axis are substantially parallel to a surface of the substrate. The mass may be substantially ring-shaped. First and second pluralities of electrode fingers may project from the mass, and third and fourth pluralities of electrode fingers projecting from the substrate and be interdigitated with the first and second pluralities of electrode fingers. The fourth plurality of electrode fingers may be positioned opposing the first plurality of electrode fingers. Fifth, sixth, seventh and eighth pluralities of electrode fingers may be similarly disposed, and the pluralities of electrode fingers are substantially co-planar. The voltage source may apply a first DC voltage between the third plurality and the fourth plurality of electrode fingers and second DC voltage, which is substantially equal in magnitude and opposite in sign, between the seventh plurality and the eighth plurality of electrode fingers.

In another aspect, the invention is directed to a method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system. The method includes rotating the mass about an input axis and causing the mass to oscillate substantially about a drive axis. The rotation of the mass about the input axis and the oscillation of the mass about the drive axis generates a Coriolis force to oscillate the mass about a sense axis. An oscillation of the mass about the sense axis is measured, a voltage is applied between electrodes associated with the substrate to cause the mass to oscillate, in the absence of a Coriolis force, more precisely about the drive axis.

In another aspect, the invention is directed to a microfabricated gyroscopic sensor. The gyroscopic sensor includes a substrate having a first plurality of electrode teeth, a vibratory structure including a second plurality of electrode teeth and a suspension system connecting the second plurality of electrode teeth to the substrate, the second plurality of electrode teeth interdigited with the first plurality of electrode teeth, a drive system to cause the vibratory structure to oscillate relative to the substrate, and a position sensor to measure a deflection of the mass caused by a Coriolis force. The first and second pluralities of electrode teeth have thicknesses substantially greater than their widths.

Implementations of the invention include the following. The suspension system may include a plurality of flexures having an aspect ratio of at least about 10:1. The first and second pluralities of electrode teeth may have an aspect ratio of at least 5:1 and may be separated by gaps having an aspect ratio of at least

10:1.

In another aspect, the invention is directed to a method of fabricating a gyroscopic sensor. An insulative layer is formed on a first substrate, a recess is formed in a first surface of a second substrate, and the first surface of the second substrate is bonded to the first substrate so that the recess defines an enclosed cavity between the first and second substrates. Circuitry for the gyroscopic sensor is formed on a second surface of the second substrate, and a plurality of trenches are etched in the second substrate from the second surface to the cavity, the plurality of trenches defining a vibratory structure connected to the first substrate.

Implementations of the invention include the following. The vibratory structure may have a thickness of at least 25 microns and the recess may have a depth of about 1 micron. The etching step may comprise a deep reactive ion etch.

Advantages of the invention include the following. The gyroscopic sensor measures rotation about an axis parallel to the surface of the substrate. The gyroscopic sensor has reduced quadrature error. The gyroscopic sensor may include a vibratory structure and interdigited electrodes with a high aspect ratio. The gyroscopic sensor has a significantly reduced noise level.

Other advantages and features of the invention will be apparent from the description which follows, including the drawings and claims.

Brief Description of the Drawings

FIG. 1 is an schematic illustration of a spring-mass system which is equivalent to an electrostatic gyroscope.

FIG. 2 is a schematic perspective view of a microfabricated gyroscopic sensor according to the present invention.

FIG. 3 is a schematic top view of the movable elements of the gyroscopic sensor of FIG. 2.

FIG. 4 is a schematic top view of the fixed elements of the gyroscopic sensor of FIG. 2.

FIG. 5 is a schematic top view of the drive system of the gyroscopic sensor of FIG. 2.

FIG. 6 is a schematic top view of the sensing system of the gyroscopic sensor of FIG. 2.

FIGS. 7A-7C are schematic illustrations of the motion of the proof mass under the influence of the Coriolis acceleration and quadrature error.

FIG. 8A is a schematic circuit diagram of an integrator used to measure the position of the proof mass in the gyroscopic sensor of FIG. 2.

FIG. 8B is a schematic circuit diagram in which the integrator of FIG. 8A is replaced by a voltage buffer.

FIG. 8C is a schematic circuit diagram in which the integrator of FIG. 8A uses a subthreshold metal oxide semiconductor field effect transistor.

FIG. 9 is a schematic illustration of the signal processing circuitry of a gyroscopic sensor according to the present invention.

FIG. 10 is a photograph of a fabricated gyroscopic sensor.

FIG. 11 is a graph illustrating the response of the gyroscopic sensor to rotation about the Z-axis.

FIG. 12 is a graph illustrating the response of the Y-axis resonant frequency to an applied bias voltage.

FIG. 13 is a graph illustrating the response of the quadrature error to an applied voltage differential.

FIG. 14 is a schematic top view of a gyroscopic sensor in which the sensing, driving and quadrature correcting functions are performed by different electrode structures.

FIG. 15 is a schematic of the circuitry of the gyroscopic sensor of FIG. 14.

FIG. 16 is a schematic illustration of a spring-mass system which is equivalent to a dual-axis electrostatic gyroscope.

FIG. 17A is a schematic top view of a dual-axis gyroscopic sensor according to the present invention.

FIG. 17B is a photograph of a fabricated dual-axis gyroscopic sensor.

FIG. 18 is a schematic illustration of the electronic circuitry of the dual-axis gyroscopic sensor of FIG. 17A.

FIG. 19 is a cross-sectional view along line 19-19 of FIG. 17A schematically illustrating the field lines generated by the quadrature correction electrodes.

FIG. 20 is a schematic top view of a dual-axis gyroscopic sensor in which the quadrature correction system includes electrode plates.

FIG. 21 is a schematic illustration of the circuitry of a gyroscopic sensor in which the sensing, driving and quadrature functions are combined in a single electrode structure.

FIG. 22 is a schematic perspective view of a gyroscopic sensor fabricated with a high-aspect-ratio vibratory structure.

FIG. 23 is a schematic circuit diagram of the signal processing circuitry of the gyroscopic sensor of FIG. 22.

FIGS. 24A-24G are schematic cross-sectional views illustrating steps in the fabrication of the gyroscopic sensor of FIG. 22.

Description of the Preferred Embodiments

Referring to FIG. 1, a Z-axis vibratory rate gyroscope functions by generating and sensing Coriolis acceleration. The functional operation of the Z-axis vibratory rate gyroscope of the present invention is illustrated by an equivalent spring-mass system. In a vibratory rate gyroscope 10, a proof mass 12 is supported by a flexible suspension 14 from a rigid frame 16. Proof mass 12 is oscillated along the X-axis (the drive mode) by a drive force F_D as the frame rotates about the Z-axis. The combination of rotation and oscillation generates a Coriolis force F_c along the Y-axis on the oscillating proof mass. The Coriolis acceleration is detected as a deflection of the proof mass along the Y-axis (the sense mode).

Referring to FIG. 2, a micromachined gyroscopic sensor 20 designed according to the present invention includes microelectromechanical sense element or proof mass 22 connected to a rigid frame or substrate 24. The gyroscopic sensor 20 measures the Z-axis vibratory rate, i.e., the rotation of the substrate about the axis normal to the micromachined surface 26 of substrate 24. The micromachined gyroscopic sensor 20 includes three major

elements: a suspension system 30, a drive system 32 used to sustain oscillation of proof mass 22 along the X-axis, and a sensing system 34 used both to detect deflections of proof mass 22 along the Y-axis and to apply electrostatic forces to cancel any quadrature error, as will be described in detail below.

Referring to FIG. 3, suspension system 30 may be formed integrally with proof mass 22. Suspension system 30 supports the proof mass so that it may vibrate in a plane parallel to surface 26. Suspension system 30 holds proof mass 22, for example, about two microns above the surface of the substrate. The total mass of proof mass 22 may be about 0.1 to 0.3 micrograms. Suspension system 30 is generally H-shaped, with two parallel beams 40 and 42 positioned generally along the X-axis. Each beam may be about 500 to 1000 microns in length, specifically about 800 microns in length. The end of each beam is connected to an anchor 44 which connects the suspension system to the substrate (see FIG. 2). The end of each beam 40, as shown in FIG. 2, may include a folded or J-shaped flexure 45 (see FIG. 3). Alternately, beams 40 and 42 may be linear.

Two beams or crossbars 46 and 48 connect beam 40 to beam 42. Crossbars 46 and 48 may be about eight-hundred microns long, and are positioned to trisect beams 40 and 42. Two cross-beams 50 and 52 connect crossbars 46 and 48. A third beam or crossbar 54 may connect the center of cross-beam 50 to the center of cross-beam 52. The flexible elements of suspension system 30 are constructed of polysilicon and, for example, have a width and a thickness on the order of two microns. The anchors may be about eight microns square.

The suspension system 30 is designed to be flexible along the X-axis and Y-axis, and as rigid as possible to other modes of vibration. In particular, the suspension system must be substantially rigid to rotation about the Z-axis, as small rotations may degrade the performance of the gyroscopic sensor. Large deflections may also result in the movable electrode fingers crashing into the stationary electrode fingers. The suspension system provides the necessary translational compliance while maintaining rotational rigidity by thickening the portions of beams 40 and 42 located between crossbars 46 and 48 to form trusses 41 and 43. Trusses 41 and 43 may have a width three to four times the width of the remainder of the beams, i.e., about six to eight microns. The portions of crossbars 46, 48 and 54 from which fingers project may have a width of approximately four microns.

The proof mass 22 also includes a plurality of finger electrodes (or simply fingers) which are used to drive and sense oscillations of proof mass along the X-axis and Y axis. A plurality of long fingers 38 project outwardly along the X-axis from crossbars 46 and 48, and a plurality of short fingers or stubs 39 project inwardly along the X-axis from crossbars 46, 48 and 54. The crossbars 46 and 48 form the spines, and long fingers 38 form the prongs of two movable sensing electrodes 56. Similarly, crossbars 46, 48 and 54 form the spines, and short fingers 39 form the prongs of two movable driving electrodes 58 and two movable feedback electrodes 59. The short fingers 39 may be about ten to twenty-five microns in length, specifically fifteen microns in length, whereas the long fingers 38 may be about one-

hundred to two-hundred microns in length, specifically one-hundred and fifty microns in length.

Referring to FIG. 4, one or more stationary driving electrodes, one or more stationary feedback electrodes, and one or more stationary sensing electrodes may be rigidly connected to substrate 24. For example, two stationary driving electrodes 60a, 60b may be arranged relative to each other in an opposing configuration. Similarly, two stationary feedback electrodes 61a, 61b may face each other in an opposing configuration. Each stationary driving electrode 60a, 60b and each stationary feedback electrode 61a, 61b includes a plurality of short fingers 66. Stationary driving and feedback electrodes 60a, 60b and 61a, 61b may have a few to dozens of fingers. Short fingers 66 may have a length of approximately 15 microns and a width of approximately three to six microns. The width, for example, may be four microns.

Two stationary sensing electrodes 62a, 62b may face each other in an opposing configuration. Stationary sensing electrodes 62a, 62b include a plurality of long fingers 70. Each long finger 70 protrudes from a base 72. The fingers of stationary sensing electrode 62a are arranged in pairs, each pair including a right finger 74a and a left finger 76a. Similarly, the fingers of stationary electrode 62b are arranged in pairs, each pair including a right finger 74b and a left finger 76b. Each long finger 70 may be approximately one hundred and fifty microns in length, and have a width of approximately four microns.

Referring to FIG. 5, drive system 32 includes movable and stationary driving electrodes 58 and 60a, 60b, and movable and stationary feedback electrodes 59

and 61a, 61b. One set of short fingers 39 is interdigitated with short fingers 66 of stationary driving electrodes 60a, 60b. Another set of short fingers 39 is interdigitated with short fingers 66 of stationary feedback electrodes 61a, 61b. Short fingers 39 of movable electrodes 58 and 59, and short fingers 66 of stationary electrodes 60a, 60b and 61a, 61b may be formed from the same layer of polysilicon prior to the removal of the sacrificial layer so that the fingers may be co-planar.

The driving electrodes of drive system 32 act as electrical-mechanical transducers. By the application of an alternating voltage between stationary driving electrodes 60a, 60b and movable driving electrodes 58, proof mass 22 may be forced to oscillate or reciprocate along the X-axis. The motion along the X-axis induces bending in crossbars 46 and 48 so that proof mass 22 may move toward and away from stationary driving electrodes 60a, 60b. A more detailed explanation of the manner of operating drive system 32 in order to sustain oscillations in proof mass 22 may be found in U.S. Pat. No. 5,025,346, issued June 18, 1991 to Tang et al., entitled Laterally Driven Resonant Microstructures, and assigned to the assignee of the present invention, the entire disclosure of which is incorporated herein by reference; and in U.S. Pat. No. 5,491,608, issued February 13, 1996 to Nguyen, entitled Q-Controlled Microresonators and Tunable Electronic Filters Using Such Resonators, and assigned to the assignee of the present invention, the entire disclosure of which is incorporated herein by reference.

Referring to FIG. 6, sensing system 34 includes stationary sensing electrodes 62a, 62b and movable

sensing electrodes 56. The long fingers 38 of movable sensing electrodes 56 and long fingers 70 of stationary sensing electrodes 62a, 62b are interdigitated, with each long finger 38 disposed between a right finger 74a, 74b and a left finger 76a, 76b of sensing electrodes 62a, 62b. The spacing, Y_o, between fingers 70 and fingers 38 may be approximately one micron. Fingers 38 and 70 may be formed from the same layer of polysilicon so that the fingers are co-planar. Thus all of the driving and sensing elements may be formed in the same fabrication step. In addition, the driving mode and the sensing mode operate in the X-Y plane parallel to the surface of substrate 24. As will be described in more detail below, sensing system 34 is used to sense the deflection of proof mass 22 along the Y-axis, to apply electrostatic forces to balance and eliminate the effect of quadrature error, and to tune the resonant frequency of Y-axis vibrations of the proof mass.

As discussed above, drive system 32 causes proof mass 22 to oscillate along the X-axis. The position of the proof mass along the X-axis, x(t), is given by the following equation:

$$x(t) = X_0 \sin\omega_x t \qquad (1)$$

where X_o is the amplitude of the oscillation and ω_x is the frequency of the driving voltage (and thus the oscillation frequency). The frequency of the driving voltage, ω_x, may be between 7 kHz and 100 kHz, and the driving voltage may be sufficient to cause the proof mass to undergo a maximum deflection, X_o, of about one micron. The magnitude of the Coriolis acceleration, $\ddot{y}_{Coriolis}$, is given by the following equation:

$$\ddot{y}_{Coriolis} = 2 \cdot \Omega_z(t) \times \dot{x}(t) \qquad (2)$$

where $\Omega_z(t)$ is the rate of rotation of the proof mass about the Z-axis and $\dot{x}$ is the velocity of the proof mass along the X-axis. Equations 1 and 2 may be combined as follows:

$$\ddot{y}_{Coriolis} = 2 \cdot \Omega_z(t) \cdot X_0 \cdot \omega_x \cdot \cos\omega_x t \qquad (3)$$

For a gyroscopic sensor with an oscillation amplitude X_0=1 μm, on oscillation frequency ω_x=20 kHz, and an input rotation rate Ω_z=1 deg/sec, the Coriolis acceleration has a magnitude of 0.45 milliG's.

The Coriolis acceleration is an amplitude-modulated signal in which the carrier frequency is the oscillation frequency and the rotation rate modulates the amplitude. The resulting Coriolis acceleration is a dual sideband signal centered on the oscillation frequency. Referring to FIG. 7A, since the Y-axis accelerations are proportional to velocity, the motion of proof mass 22 is elliptical. The maximum deflection of proof mass 22 along the Y-axis will be a few nanometers. The deflection detectable by gyroscopic sensor 20 may be on the order of a picometer.

In an ideal device, the moving electrodes are perfectly aligned with the stationary electrodes so that the only motion caused by drive system 32 is along the X-axis. However, one effect of manufacturing flaws is quadrature error. Referring to FIG. 7B, quadrature error occurs if proof mass 22 oscillates along an axis that is not exactly parallel to the X-axis. If this is the case, then there is some small fraction, ε, of the drive oscillation, X(t), which lies along the Y-axis. This

quadrature displacement along the Y-axis is given by the following equation:

$$y_{Quadrature} = -\varepsilon \cdot x(t) \tag{4}$$

If this displacement is differentiated twice, the acceleration, $\ddot{y}_{quadrature}$, due to off-axis oscillation can be determined. This acceleration, given in Equation 5 below, is referred to as quadrature error.

$$\ddot{Y}_{Quadrature} = \varepsilon \cdot X_0 \cdot \omega_x^2 \cdot \sin\omega_x t \tag{5}$$

Note the similarity between the quadrature error and the Coriolis acceleration: both are sinusoidal signals centered at the frequency of oscillation. However, the signals can be distinguished by their phase relative to the driven oscillation. Specifically, the Coriolis acceleration is ninety degrees out of phase relative to the drive oscillation, ω_x, whereas the quadrature error is in phase with the driven oscillation.

The quadrature error can be quite large. In fact, the quadrature error may easily exceed the Coriolis acceleration. The ratio of quadrature error and Coriolis acceleration is given by Equation 6:

$$\frac{\ddot{Y}_{Coriolis}}{\ddot{Y}_{Quadrature}} = \frac{2\Omega_z(t) \cdot X_0 \cdot \omega_x}{\varepsilon \cdot X_0 \cdot \omega_x^2} = \frac{2\Omega_z(t)}{\varepsilon \cdot \omega_x} \tag{6}$$

Using the previous example of an input rotation rate, Ω_z, of 1 deg/sec and an oscillation frequency, ω_x, of 20 kHz, for the quadrature error to be as small as the Coriolis acceleration, the oscillation direction must be accurate to a factor of 1 part in 3.6 million. Due to manufacturing flaws and other imbalances, the quadrature error may be considerably larger than this. Accordingly,

gyroscopic sensor 20 has a mechanism to reduce, or nullify the quadrature error.

Microfabricated gyroscopic sensor 20 may apply electrostatic forces to proof mass 22 through sensing system 34. By selection of the proper electrostatic force, the quadrature error may be nullified. As shown by Equation 5, the quadrature error is directly proportional to position of the proof mass along the X-axis. To cancel this error signal without effecting the Coriolis signal, a balancing force must be applied that is also directly proportional to the position of the proof mass along the X-axis. Gyroscopic sensor 20 applies such a balancing force, using the interdigitated Y-axis position sense fingers.

Referring to FIG. 7C, proof mass 22 is shown with two fingers 38a and 38b projecting from opposite sides of the proof mass. Finger 38a is surrounded by right and left fingers 74a and 76a, whereas finger 38b is surrounded by right and left fingers 74b and 76b. A small voltage differential, $2\Delta V$, is applied between the right finger 74a and left finger 76a. The opposite voltage potential $-2\Delta V$, may be applied between right finger 74b and left finger 76b. This voltage difference creates a balancing force, F_y, which counteracts the quadrature error. The balancing force acts on proof mass 22 so that, absent the Coriolis force, fingers 39 vibrate solely along the X-axis. As mentioned above, the balancing force needs to be exactly proportional to the position of the proof mass along the X-axis. An electrostatic force between two charged surfaces is proportional to the overlapping area of the surfaces. Because the overlapping area between fingers 38 and fingers 70 is directly proportional to the position of

proof mass 22 along the X-axis, as proof mass oscillates, the position sense capacitors change proportionately. Therefore, the electrostatic balancing force F_y will also be proportional to the position of proof mass 22. Sensing system 34 applies a DC bias voltage V_{DC} to fingers 74a, 74b, 76a and 76b and a voltage differential $Z\Delta V$ between fingers 74a, 74b and 76a, 76b given by Equation 7 below:

$$F_y = \frac{C_{overlap}}{y_0} x(t) \cdot ((V_{DC}+\Delta V)^2 - (V_{DC}-\Delta V)^2) = 2\frac{C_{overlap}}{y_0} V_{DC} \Delta V \cdot x \qquad (7)$$

where $C_{overlap}$ is the maximum change in capacitance between fingers 70 and fingers 38 as the structure oscillates and y_0 is the equilibrium distance between fingers 70 and fingers 38.

By properly selecting the voltage differential ΔV, the quadrature error may be significantly reduced, e.g., by a factor ten to one-hundred. The proper voltage difference may be calculated from Equations (7) and (5) and Newton's law F = ma, as follows:

$$\Delta V = M\frac{\varepsilon y_0 \omega_x^2}{V_{DC} C_{overlap}} \qquad (8)$$

where M is the mass of proof mass 22. Because the quadrature error is a result of manufacturing defects, the proper voltage differential depends upon the specific structure and may vary from device to device. A voltage differential in the range of 1 mV to 100 mV should be appropriate. The optimum voltage differential to cancel the quadrature error may be determined experimentally (see FIG. 13 which is discussed below).

In addition to canceling the quadrature error, sensing system 34 of gyroscopic sensor 20 may be used to match the Y-axis resonant frequency ω_y of proof mass 22 to the driving oscillating frequency ω_y. Because gyroscopic sensor 20 is a high Q second order system, the response of proof mass 22 to Coriolis acceleration can be enhanced. As shown by Equation 3, the Coriolis acceleration is a signal centered around the oscillation frequency ω_x. Therefore the relative values of the oscillation frequency ω_x and the Y-axis resonant frequency ω_y have a dramatic effect on the response of the sense mode and hence the sensor sensitivity. If the Y-axis resonant frequency is matched to the oscillation frequency, the device may experience a gain of Q in the system response. However, the bandwidth of the sensor is then limited to ω_y/Q. Given that system is run in a vacuum and Q is typically greater than 10,000, the system bandwidth for $\omega_x=\omega_y$ will be only a few Hertz.

For larger bandwidth and increased sensitivity, gyroscopic sensor 20 is operated with a slight mismatch between resonant frequency ω_y and oscillation frequency ω_x. The system response of Y-axis displacement due to Coriolis acceleration is given by:

$$\frac{y}{\Omega_z} = \frac{2X_0\omega_x \sin\omega_x t}{\omega_y^2 + \frac{j\omega_x\omega_y}{Q} - \omega_x^2} = \frac{X_0\omega_x}{\omega_x\Delta\omega}\sin\omega_x t \qquad (9)$$

Provided that there is a means to tune the Y-axis resonant frequency, it is desirable to operate the gyroscopic sensor with a 5-10% frequency mismatch, $\Delta\omega/\omega_x$, yielding a gain of 5-10 in sensitivity. For example, if ω_x is about 12 kHz, then ω_y may be set to about 12.5 kHz. Alternately, the frequency mismatch may be reduced to

about 1-2%. Reducing the mismatch further might increase the sensitivity but may be difficult to maintain for any length of time because the resonant frequency changes as the temperature of the gyroscopic sensor changes.

Tuning of the Y-axis resonant to improve sensitivity is accomplished using electrostatic "negative" springs, i.e., by applying a DC bias voltage, V_{DC}, between proof mass 22 and stationary sensing electrodes 62. When the DC voltage is established between the moving proof mass and the stationary sensing electrode, the resulting attractive force reduces the total spring constant and thus adjusts the resonant frequency.

Using a first-order model for the parallel-plate capacitors, the linearized spring force due to electrostatic forces is given by:

$$F_y = \left[\frac{1}{(y_0-y)^2} - \frac{1}{(y_0+y)^2}\right]\frac{y_0 C_s V_{DC}^2}{2} \qquad (10)$$

where y is the deflection of the proof mass along the Y-axis away from its equilibrium position.

The Y-axis resonant frequency, ω_y, is given by the following equation:

$$\omega_y = \sqrt{\frac{k_y+k_e}{M}} \qquad (11)$$

where k_y is the purely mechanical spring constant, k_e is the electrostatic spring constant and M is the mass of proof mass 22. The mechanical spring constant k_y is primarily a function of the stiffness of suspension system 30.

The electromagnetic spring constant, k_e, is given by the following equation:

$$k_e = -2\frac{C_s}{y_0^2}V_{DC}^2 \qquad (12)$$

in which C_s is the sense capacitance of the gyroscopic sensor and y_o is the distance between fingers 38 and 70 (see FIG. 7A). C_s depends upon the total number of fingers and the amount of overlapping area, and should be at least 30 femtoFarads (fF). By increasing the number of fingers, C_s may be increased to about one picoFarad (pF). As mentioned above, the spacing y_o between fingers is about one micron. It may be noted that k_e has a negative value, so that as V_{DC} is increased ω_y is decreased. The system starts with ω_y larger than ω_x, and the bias voltage V_{DC} is increased, thereby reducing ω_y, until the desired mismatch $\Delta\omega/\omega_y$ is achieved. The correct valve for V_{DC} may be determined experimentally (see FIG. 12 which is discussed below), but should be in the range of one to ten volts.

In addition to canceling the quadrature error and adjusting the Y-axis resonant frequency, sensing system 34 may be used to negate the effects of centrifugal or centripetal force. As the gyroscope sensor rotates about the Z-axis, a centrifugal force will push the proof mass outwardly (assuming the axis of rotation does not pass exactly through the center of mass of the proof mass). A voltage difference, V_c, may be applied between the opposing stationary sensing electrodes 62a and 62b. Because the centripetal force varies at a low frequency, compared to the frequencies of the Coriolis force, a high pass filter may be used to remove the effect of the centripetal force from the output.

Gyroscopic sensor 20 measures the position of proof mass 22 along the Y-axis by capacitive deflection sensing. The interdigitated fingers of sensing system 34 (shown in FIG. 2) are used to sense deflection of the proof mass along the Y-axis. The fingers are arranged in a capacitor bridge so that any deflection of the proof mass results in measurable changes in the relative size of the capacitors. In a first order model, the capacitance of a parallel-plate capacitor is inversely proportional to the distance between the plates.

Referring to FIGS. 6 and 8A, the space between finger 38 of movable sensing electrode 56 and right fingers 74a, 74b of sensing electrodes 62a, 62b forms a first capacitor C_1, and the space between finger 38 and left fingers 76a, 76b forms a second capacitor C_2. As movable sensing electrode 56 is deflected along the Y-axis, C_1 and C_2 change. For example, if sensing electrode 56 is deflected leftward, the distance between finger 38 and right fingers 74a, 74b increases, thereby decreasing C_1, while the distance between finger 38 and left fingers 76a, 76b decreases, thereby increasing C_2. The change in capacitance is detected by a position sensor 80, such as an integrator or voltage buffer, which includes an amplifier 82. Finger 38 is connected to the negative input of amplifier 82. The output of amplifier 82 is connected to the negative input of the amplifier via an integrating capacitor 84 to form an integrator. The negative input of amplifier 82 is connected to ground via a parasitic capacitor 83. The positive input of amplifier 82 may be connected directly to ground.

Because capacitance cannot be measured with a DC voltage, a voltage source 90 applies an AC voltage V_S between fingers 74a, 74b and 76a, 76b. The voltage V_S is

about 0.1 to 5.0 volts, preferably about one volt, and has a frequency much higher than the driving frequency ω_x. For example, the frequency of voltage source 90 may be about one megahertz.

The integrator shown in FIG. 8A offers the flexibility of trading bandwidth for sensitivity by varying the integrating capacitor size. The integrator also provides lower distortion. Some of the parasitic capacitors involved in microelectromechanical systems are nonlinear which will vary the gain of a buffer and thereby result in distortion, and the practice of bootstrapping parasitic capacitance is a form of positive feedback which exacerbates amplifier distortion. However, because the integrator uses a fixed, linear capacitor, distortion is kept to a minimum.

Another common amplifier configurations used for capacitive position sensing is shown in FIG. 8B, in which the output of amplifier 82 is connected to its negative input and sensing electrodes 56 are connected to the positive input of the amplifier to form a voltage buffer.

Unfortunately, the integrator presents a difficult biasing problem. Ideally, biasing can be performed by placing a very large resistor in parallel with the integrating capacitor. However, any practical implementation of a large resistor results in a considerable parasitic capacitance. A diode can also be used in parallel with the integrating capacitance; however, that adds a nonlinear capacitance to the integrating capacitance resulting in distortion. Referring to FIG. 8C, this biasing problem has been solved by using a subthreshold metal oxide semiconductor field effect transistor (MOSFET) 88. The MOSFET device is connected in parallel with integrating capacitor 84 so

that the source of MOSFET 88 is connected to the output of amplifier 82, the drain is connected to the negative input of amplifier 82, and the gate is connected to ground. The negative input of amplifier 82 may be connected to ground by a diode 86, and the positive input of amplifier 82 may be connected directly to ground. In the subthreshold regime, the MOSFET device exhibits extremely low transconductance and no source-to-drain capacitance. The use of subthreshold MOSFET device has resulted in a well behaved integrator operable down to 1 kHz with a 50 F integrating capacitor without additional noise or distortion attributable to the bias circuitry.

Referring to FIG. 9, gyroscopic sensor 20 includes a phase-locked loop (PLL) 100 and several synchronous demodulators or mixers to perform signal processing. Phase-locked loop 100 produces extremely accurate digital signals having a driving frequency ω_x between about 7 kHz and 100 kHz. The drive frequency, ω_x, may be generated by dividing down the signal from voltage source 90. The phase-locked loop ensures that the position signals are exactly in phase with the position of proof mass 22. Phase-locked loop 100 may also generate a velocity signal on line 108 which is exactly ninety degrees out of phase with a position signal on line 110. Position signals on lines 102 and 104, having opposite amplitudes, are supplied by phase-locked loop 100 to the positive and negative outputs, respectively, of a transresistance amplifier 106. Opposing stationary drive electrodes 60a and 60b are also connected to the positive and negative outputs of transresistance amplifier 106. Opposing feedback electrodes 61a and 61b are connected to the positive and negative inputs of transresistance amplifier 106. One of the outputs of transresistance amplifier 106

is mixed with the velocity signal by a mixer 112. The combined output of mixer 112 is applied to trans-resistance amplifier 106 to provide an automatic gain control (AGC) circuit to control the amplitude of the oscillations of proof mass 22 along the X-axis. The phase accuracy of the phase-locked loop is critical to the operation of gyroscopic sensor 20 because any phase error will result in cross-talk between the Coriolis and quadrature signals. Assuming that a phase error $\theta_n(t)$ is generated by phase noise in the phase-locked loop, the error in the rotation rate Ω may be derived as shown in Equations 13-15 below:

$$y(t) = [\frac{X_0\omega_x}{\omega_x\Delta\omega}\Omega\cos\omega t + Y_{Quadrature}\sin\omega t] \quad (13)$$

$$\Omega_{est} = \frac{\omega_x\Delta\omega}{X_0\omega_x}y(t)\cos(\omega_x t+\theta_n(t)) \quad (14)$$

$$\Omega_{est} = \Omega + \frac{\omega_x\Delta\omega}{X_0\omega_x}Y_{Qadrature}\theta_n(t) + Higher\ terms \quad (15)$$

Because phase-locked loop 100 is extremely accurate, phase noise is minimized and variable cross-talk is extremely small. In addition, quadrature error correction reduces cross talk and phase noise.

The nulling of the quadrature error, the tuning of the Y-axis resonant frequency, and the balancing of the centrifugal forces is accomplished by the application of the proper voltages to fingers 70 of opposing stationary sensing electrodes 62a and 62b. Specifically, gyroscopic sensor 20 includes four DC bias voltage sources 120, 122,

124 and 126. Voltage source 120 applies a total voltage $V_t=V_{DC}+\Delta V+V_C$ to right fingers 74a of sensing electrode 62a. Voltage source 122 applies a total voltage of $V_{DC}-\Delta V-V_C$ to left fingers 76a. Voltage source 124 applies a total voltage of $V_{DC}-\Delta V+V_C$ to right electrode fingers 74b of sensing electrode 62b. Voltage source 126 applies a total voltage of $V_{DC}+\Delta V-V_C$ to left fingers 76b. Thus, voltage sources 120, 122, 124 and 126 provide all of the necessary bias voltages in order to nullify the quadrature error, select the desired Y-axis resonant frequency, and cancel any centrifugal or other low-frequency forces. Of course, any other combination of voltage sources providing the same effective total voltage to the fingers of the sensing electrodes could be used. Also, the voltages could be applied by different sets of fingers of the stationary sensing electrode, for example, V_{DC} could be applied by one set of fingers and ΔV could be applied by another set of fingers.

In order to extract the position, Coriolis effect, and quadrature signals from capacitive position sensor 80, the signal from amplifier 82 is boosted by an oscillation amplifier 130 to produce an output signal on line 132. This output signal may be mixed with signals from a modulator or clock and the position and velocity signals from phase locked loop 100. Voltage source 90 may produce a high frequency, e.g., one megahertz clock signal on line 134. To generate the position signal, this clock signal is mixed with the output signal on line 132 by a mixer 136. In order to produce the Coriolis signal, the clock signal on line 134 is mixed with the velocity signal on line 108 by a mixer 140 to produce a combined signal on line 142. The combined signal on line 142 is then mixed with output signal on line 132 by a

mixer 144 to produce the Coriolis signal. Finally, to produce the quadrature signal, the clock signal on line 134 is mixed with the position signal on line 110 by a mixer 150 to produce a combined signal on line 152. The combined signal on line 152 is then mixed with output signal on line 132 by a mixer 154 to produce the quadrature signal. The position, Coriolis and quadrature signals may be passed through low pass filters to filter out high frequency components.

Referring to FIG. 10, a gyroscopic sensor 20 was fabricated on a silicon substrate 24 using a combination of metal oxide semiconductor and microelectromechanical fabrication techniques. The transresistance amplifier and integrator were fabricated on the same die, and the remaining electronics was implemented off of the chip. The mechanical sensing element is about one millimeter across.

There are a number of possible noise sources in gyroscopic sensor 20. Principal among these are: Brownian noise, op-amp noise in the integrator, and phase locked loop phase noise. The Brownian noise, $\Omega_n B$, represents the fundamental limit on angular rate resolution and is given by:

$$\Omega_{nB} = \sqrt{\frac{kT\omega_y BW}{MQ\omega_x^2 X_0^2}} \qquad (16)$$

where k is Boltzman's constant, T is the temperature, M is the mass of the proof mass, BW is the bandwidth of the gyroscopic sensor, and Q is the quality factor. As an example, consider a gyroscopic sensor with mass, M=0.2μg, an oscillation amplitude X_0=1 μm, a quality factor, Q= 10,000, a bandwidth BW = 100 Hz, a drive frequency ω_x= 20

kHz and a resonant frequency ω_y= 20 kHz. For this example, we find a Brownian noise floor Ω_{nB}=0.06 deg/sec. Because the gyroscopic sensor is run in vacuum and has a high Q, Brownian noise is not the dominant noise source.

As shown by Equation 15, phase noise in the phase locked loop, represented by $\theta_n(t)$, can cause variable cross talk between quadrature and Coriolis signals. In gyroscopic sensor 20, this effect is kept to a minimum due to the low phase noise in the phase locked loop and nulled quadrature error.

The integrator op-amp noise is the dominant noise source in gyroscopic sensor 20. The input-referred noise, Ω_E, of the op-amp noise is a function of the total capacitance, C_T, attached to the summing node of the integrator, and is given by:

$$\Omega_{nE} = \frac{C_T Y_0 v_n}{C_S X_0 V_S}\Delta\omega\sqrt{2BW} = \frac{Y_0\Delta\omega}{X_0 V_S}\sqrt{\frac{32kTBW}{3\pi C_S f_T}} \qquad (17)$$

where f_T is the maximum operable frequency of the transistors in gyroscopic sensor 20. The electronic noise is at best Ω_{nE}=0.08 deg/sec for a modest CMOS process with f_T=250 MHZ, a frequency mismatch $\Delta\omega$=1 kHz, a sense voltage V_s=1 volt, a sense capacitance C_s=100fF, and the oscillation amplitude and finger spacing X_0=y_o=1 μm.

An initial characterization of the gyroscopic sensor response is shown in FIG. 11. FIG. 11 is a graph of the logarithm of the output voltage of the Coriolis signal, on the Y-axis, as a function of frequency, on the X-axis. The graph was produced by measuring the output Coriolis signal in response to a 1Hz, 5 deg/sec sine wave rotation. The gyroscopic sensor was operated with an oscillation frequency, ω_x, of 12 kHz and a Y-axis resonant frequency, ω_y, of about 12.5 kHz. The noise floor for

this version of Z-axis vibratory rate gyroscopic sensor is 1 deg/sec/Hz^{½}.

Referring to FIG. 12, there is a measured mechanical resonant frequencies of proof mass 22 as a function of the DC bias voltage applied to the position sense fingers. FIG. 12 shows a graph of the resonant frequencies of proof mass 22 (on the Y-axis of the graph) as a function of the RMS voltage (on the X-axis of the graph) applied between fingers 38 and fingers 70. The RMS voltage is a combination of the DC bias voltage and the AC voltage generated by voltage source 90. The resulting electrostatic springs reduce the resonant frequency of the sense mode (ω_y), raise the resonant frequencies of the out-of-plane modes, and leaves the driven mode (ω_x) unaffected. As expected, the Y-axis resonant frequency drops as the bias voltage is increased and the oscillation frequency of proof mass 22 remains constant at 12kHz. The resonant frequencies of the vertical and tipping modes increase with DC bias due to electrostatic levitation effects.

As discussed above, gyroscopic sensor 20 includes a means to null quadrature error. FIG. 13 shows a graph of the measured voltage, V_{out} on the Y-axis, as a function of the voltage differential, ΔV, on the X-axis, which is applied between right fingers 74a, 74b and left fingers 76a, 76b. Both the quadrature and rotation rate signals were plotted for a zero rotation rate as ΔV was adjusted. Measurements of the quadrature error and rotation rate signals demonstrate that the quadrature error signal can be controlled independently of the Coriolis signal.

Another embodiment of the gyroscopic sensor, in which the sensing and quadrature correction voltages are applied by different electrode fingers, is shown by FIG.

14. Referring to FIG. 14, a micromachined gyroscopic sensor 200 includes a proof mass 202 connected to a substrate 204 by a suspension system 206. The gyroscopic sensor 200 includes three major electronic elements: a drive system 210 used to sustain oscillation of proof mass 202 along the X-axis, a sensing systems 212 used to detect deflections of proof mass 202 along the Y-axis, and a quadrature correction system 214 used to cancel any quadrature error.

The proof mass 202 includes a rectangular outer stage 220 and a rectangular inner stage 222. Each corner of outer stage 220 is connected by a folded or J-shaped first flexure 224 to an anchor 226 which secures proof mass 202 and suspension system 206 to substrate 204. Similarly, each corner of inner stage 222 is connected to outer stage 220 by a second flexure 228. The first flexure 224 is designed to permit outer stage 220 to vibrate primarily along a Y-axis with respect to substrate 204, whereas second flexure 228 is designed to permit inner stage 222 to vibrate substantially along the X-axis with respect to outer stage 220. Several beams or crossbars 230 may connect opposing sides of inner stage 222.

The physical characteristics of gyroscopic sensor 200 are similar to those of gyroscopic sensor 20. The sensor may be about 0.5 to 2.0 millimeters on a side; the proof mass may have a total mass of about 0.1 to 0.5 micrograms; the flexible elements of the suspension system may be constructed of polysilicon and may have a width and a thickness on the order of two microns. The entire assembly may be fabricated using traditional integrated circuit fabrication techniques.

Referring to FIG. 14, the drive system 210 includes two driving electrodes 232a and 232b, and two feedback electrodes 234a and 234b, all connected to substrate 204. A plurality of electrode fingers 236 project along the X-axis from each feedback electrode and each drive electrode. A plurality of electrode fingers 238 project from inner stage 222 of proof mass 202 along the X-axis, and are interdigitated with electrode fingers 236 of the sense and drive electrodes.

As shown in FIG. 15, feedback electrodes 234a and 234b are connected to the positive and negative inputs, respectively, of a transresistance amplifier 240. The driving electrodes 232a and 232b are connected to the positive and negative outputs of transresistance amplifier 240, respectively, and to a phase-locked loop 242, as previously described with respect to FIG. 9.

The sensing system 212 includes a plurality of pairs of sense electrodes fingers aligned with the X-axis. Each pair of sense electrode fingers includes a right finger 244 and a left finger 246. A plurality of electrode fingers 248 are connected to outer stage 220 and are interdigited so that each electrode finger 248 is disposed between one right finger 244 and one left finger 246. A sense voltage source 250 (see FIG. 15) applies an AC voltage between the right fingers 244 and the left fingers 246.

Quadrature correction system 214 includes several sets of correction electrodes positioned near the center-line of the sensor and connected to the substrate. Each set of correction electrodes includes an upper left electrode 260, an upper right electrode 262, a lower left electrode 264, and a lower right electrode 266. Upper right electrode 262 and lower left electrode 264 may be a

single electrode, as shown, or may be separate electrodes. A plurality of electrode fingers 268 extend from crossbars 230 and are interdigited with the connection electrodes. Specifically, each electrode finger 268 extends along the X-axis from crossbar 230 and is disposed between upper left electrode 260 and upper right electrode 262. Similarly, each electrode finger 268 extends along the X-axis from crossbar 230 and is disposed between lower left electrode 264 and lower right electrode 266. Upper left electrode 260 is electrically connected to lower right electrodes 266, and upper right electrode 262 is electrically connected to lower left electrode 264.

A voltage source 270 (FIG. 15) applies a DC bias voltage between the correction electrodes 260, 266 and 262, 264. The voltage differential between the left and right electrodes creates a balancing force to counteract the quadrature error as discussed with respect to FIG. 7C. The remainder of the circuitry, including an integrator 280 and mixers 282-286 may be assembled and function in a manner similar to the circuitry discussed above with reference to FIG. 9.

Referring to FIG. 16, quadrature correction may be used to compensate for manufacturing flaws that occur in the fabrication of other sorts of gyroscopic sensors, such as X-axis and Y-axis gyroscopic sensors. A dual-axis vibratory gyroscope functions by generating and sensing Coriolis accelerations. The functional operation of the dual-axis vibratory gyroscope is illustrated by an equivalent spring-mass system. In a dual-axis gyroscopic sensor 290, a proof mass 292 is supported by a flexible suspension 294 from a frame 296. The proof mass is generally disc-shaped, and lies in a plane generally

parallel to the surface of the substrate. The proof mass is oscillated about the Z-axis (the axis perpendicular to the surface of the substrate) by a drive torque F_d with a frequency ω_z. If the frame rotates about a first axis parallel to the surface of the substrate, e.g., the Y-axis, at a rotation rate Ω_Y, then the combination of this rotation and oscillation generates an oscillating Coriolis torque F_c about a second axis parallel to the surface of the substrate and perpendicular to the first axis, i.e., the X-axis. This Coriolis force torque will tend to oscillate the proof mass about the X-axis at a frequency ω_X. Thus, rotation of the proof mass about the Y-axis causes the proof mass to undergo a "see-saw" motion about the X-axis. Similarly, a rotation about the X-axis will induce a Coriolis oscillation about the Y-axis.

The Coriolis acceleration about the X-axis generated by rotation of the proof mass about the Y-axis is given by the following equation:

$$I_{xx}\ddot{\theta}_x + C_x\dot{\theta}_x + K_x\theta_x = -I_{zz}\Omega_y \times \theta_{z0}\omega_z \cos(\omega_z t) \qquad (18)$$

where θ_x is the sense-axis tilt angle, I_{xx} is the X-axis moment of inertia, C_x is the damping co-efficient, K_x is the spring constant, ω_z is the frequency of oscillation about the Z-axis, I_{zz} is the Z-axis movement of inertia, and Ω_y is the rotation rate of the proof mass about the Y-axis. The angular oscillation of the rotor caused by the Coriolis acceleration can be thought of as an amplitude modulated signal with a carrier frequency ω_z. The amplitude of the modulated signal is directly proportional to the Y-axis rotation rate Ω_y. The equation for Coriolis acceleration about the Y-axis is essentially

identical except that the x and y subscripts are reversed and the right-hand side of the equation is positive.

Referring to FIG. 17A, a dual-axis gyroscopic sensor 300 includes a generally ring-shaped proof mass 302 connected to a rigid frame or substrate 304 by a suspension system 306. Dual-axis gyroscopic sensor 300 measures the X-axis and Y-axis rotation rate; i.e., the rotation of the substrate about the axes parallel to the surface of substrate 304. Dual-axis gyroscopic sensor 300 includes three major electronic elements: a drive system 310 used to sustain oscillation of proof mass 302 about the Z-axis, a sensing system 312 used to detect deflections of proof mass 302 about the X-axis and Y-axis, and a quadrature correction system 314 used to cancel any quadrature error. The dual-axis gyroscopic sensor 300 may be fabricated using standard integrated circuit techniques.

The proof mass 302 includes a generally ring-shaped rotor 316. Rotor 316 may be a two micron thick polysilicon ring with an outer radius of about 250 microns and an inner radius of about 200 microns. The proof mass 302 is substantially symmetric about the X- and Y-axis.

The suspension system 306 may include four beams 320 which connect an inner edge 322 of the proof mass to an anchor 324 which secures rotor 316 to substrate 304. The beams 320 may also be constructed of polysilicon and may have a width and thickness on the order of two microns.

Alternately, the suspension system may include a serpentine suspension with folded beams. In yet another version, the proof mass may be suspended by four beams connected to an outer edge of the rotor. A serpentine

suspension system provides a lower natural frequency and can accommodate warping of the rotor.

Suspension systems 306 is designed to provide a torsional suspension for rotor 316 to allow rotation about the three perpendicular axes. However, suspension system 306 is designed to be rigid to translational accelerations along the X-axis and the Y-axis. Although rotor 316 may undergo translational acceleration along the Z-axis, the differential sensing scheme discussed below substantially cancels sensitivity to such accelerations.

For maximum mechanical sensitivity, the suspension system is designed to match the frequencies of all three rotational modes sufficiently well that electrostatic tuning may compensate for process variations during manufacture of the gyroscope sensor. In particular, the sense axis natural frequencies were designed to be about ten percent above the drive natural frequencies so that the sense frequencies may be down tuned to match the drive frequency.

A plurality of inner combs 330a-330d project inwardly from inner edge 322 of rotor 316. Each inner comb includes a spine 332 and a plurality of teeth 334 which project from both sides of the spine. The number and configuration of inner combs in FIG. 17A is merely illustrative. The dual axis gyroscope may include twelve inner combs, each having five teeth. Four outer combs 340a-340d project outwardly from an outer edge 326 of rotor 316. Each outer comb includes a spine 342 and a plurality of teeth 344 projecting from both sides of the spine. Although teeth 334 and 344 in FIG. 17A are illustrated as linear, as shown in FIG. 17B it is

advantageous for the teeth to be constructed as portions of arcs from concentric circles.

As previously mentioned, drive system 310 induces oscillations of proof mass 302 about the Z-axis. The drive system 310 includes one or more drive electrodes 350a-350b and one or more feedback electrodes 352a-352b connected to substrate 304. Preferably, the drive and feedback electrodes are arranged in opposing pairs located on either side of each inner comb 330a-330d. Each feedback and drive electrode includes a plurality of teeth 354 which are interdigited with teeth 334 of the adjacent inner comb. Teeth 354 may have an arc length of approximately twenty microns and a width of approximately two microns. The drive electrodes of drive system 310 act as electrical, mechanical transducers. By application of an alternating voltage between the drive electrodes and the proof mass, the proof mass may be forced to oscillate about the Z-axis. Specifically, beams 320 may flex or bend so that rotor 316 may rotate.

Referring to FIG. 18, dual-axis gyroscopic sensor 300 includes a transresistance amplifier 366 which produces drive signals 362 and 364 having a driving frequency ω_z of about twenty to thirty kilohertz. Drive signals 362 and 364 are equal in magnitude but opposite in sign. phase-locked loop 360. A phase-locked loop 360 generates an extremely accurate digital output signal on line 368 which is in phase with the rotational rate of the proof mass. The opposing feedback electrodes 352a and 352b are connected to the positive and negative inputs of trans-resistance amplifier 366. The opposing drive electrodes 350a and 350b are connected to the positive and negative outputs 362 and 364 of trans-resistance amplifier 366 and to phase-locked loop 360.

The positive and negative outputs of trans-resistance amplifier 366 are also mixed with the digital output signal on line 368 by a mixer 370. The output of mixer 370 is then used to modulate trans-resistance amplifier 366. This modulation provides an automatic gain control circuit to control the amplitude of the oscillations of proof mass 302. Thus, drive system 310 provides a phase-locked oscillation of constant amplitude to the proof mass and provides a clean signal for Coriolis demodulation.

Returning to FIG. 17A, sensing system 312 includes four sense electrodes 374a-374d (shown in phantom because they are located beneath the rotor 316). Each sense electrode is shaped as a quarter-pie section and may be formed of an n+ diffused region in substrate 304. Sense electrodes 374a and 374c are positioned along the X-axis whereas the sense electrodes 374b and 374d are positioned along the Y-axis. The Coriolis oscillation is measured by sensing the change in capacitance between rotor 316 and sense electrodes 374a-374d. For example, if the gyroscopic sensor rotates about the Y-axis, then the Coriolis force may cause the right portion of rotor 316 to move closer to sense electrode 374b and the left portion of rotor 316 to move farther away from sense electrode 374d. Thus, the capacitance between sense electrode 374b and rotor 316 increases whereas the capacitance between sense electrode 374d and rotor 316 decreases. Because each pair of opposing sense electrodes provides differential sensing, translation of the rotor up or down along the Z-axis does not change in sense output.

Referring to FIG. 18, a first sense voltage source 376 connects opposing sense electrodes 374a and 374c, and

a second sense voltage source 378 connects opposing sense electrodes 374b and 374d. The sense voltage sources 376 and 378 generate AC voltages with different modulation frequencies. For example, one voltage source may operate at 200 kHz and the other voltage source may operate at 300 kHz. In order to extract the position signals indicating the angular position of rotor 316 about the X-axis and Y-axis, proof mass 302 is electrically connected to an integrator 380. The integrator 380 may include a capacitor 381 having a capacitance of about 50 femtoFarrads. A benefit of integrator 380 is that it improves linearity.

The output of integrator 380 is demodulated with the signal from sense voltage source 376 by a mixer 382. The output from integrator 380 is also demodulated with the signal from sense voltage source 378 by a mixer 384. The outputs of mixers 382 and 384 are then demodulated by mixers 386 and 388 with the digital output signal on line 368 from phase-locked loop 360. The output of mixer 386 provides the angular rotation rate of the gyroscopic sensor about the X-axis, and the output of mixer 388 provides the rotation rate of the gyroscopic sensor about the Y-axis.

The combined mechanical and electrical sensitivity of dual-axis gyroscopic sensor 300 may be calculated according to the following equation:

$$\left|\frac{V_{out}}{\Omega_y}\right| = \left|\frac{\theta_x}{\Omega_y}\right|\left|\frac{V_{out}}{\theta_x}\right| = \left|\frac{2\theta_{z0}\omega_z}{\omega^{2}_{x} + \frac{j\omega_x\omega_z}{Q_x} - \omega^{2}_{z}}\right|\left|2\frac{\partial C}{\partial\theta_x}\frac{V_s}{C_I}\right| \qquad (19)$$

were V_s is the sense voltage, C_i is the capacitance of the integrating capacitor, Q_x is the quality of inverse

damping coefficient, and V_{out} is the voltage signal from the mixer. One drawback of the sensing system is that a small inherent voltage is generated at twice the drive frequency. However, this voltage is far from the sense modulation frequencies.

As described above, if dual-axis gyroscopic sensor 300 is rotating about an axis parallel to the surface of the substrate, then the oscillation of rotor 316 about the Z-axis induces an oscillation about the X-axis or Y-axis due to the Coriolis force. In an ideal device, rotor 316 is perfectly aligned so that the only motion caused by drive system 310 is within the X-Y plane. However, fabrication imperfections may cause rotor 316 to wobble as it undergoes rotation about the Z-axis. Specifically, even if the gyroscopic sensor 300 is not rotating about the X-axis or Y-axis, as rotor 316 rotates about the Z-axis, it may oscillate or wobble out of the X-Y plane. The wobble caused by the fabrication imperfections generates a false rotation rate measurement called quadrature error. The quadrature error in dual-axis gyroscopic sensor 300 is similar to the quadrature error in Z-axis gyroscopic sensor 20; the quadrature error and Coriolis acceleration are both sinusoidal signals centered at the frequency of oscillation and ninety degrees out of phase. Ideally, demodulation will eliminate the out-of-phase quadrature error. However, because the electronic components may have a small phase-lag, some percentage of the quadrature error will corrupt the measurement of the rotation rate.

Returning to FIG. 17A, quadrature correction system 314 includes eight correction electrodes 390a-390h. The correction electrodes are arranged in pairs with each outer comb 340a-340d surrounded by two opposing

correction electrodes. For example, outer comb 340a is flanked by correction electrodes 390a and 390b. Each correction electrode has a plurality of teeth 392 which are interdigitated with the teeth of the outer combs. The quadrature correction system 314 may apply voltages to the correction electrodes 390a-390h in order to levitate teeth 344 of the outer combs and cancel the quadrature error.

Returning to FIG. 18, each pair of opposing correction electrodes may be connected to a DC offset voltage source. In addition, the correction electrodes on opposite sides of the rotor may be connected. For example, correction electrode 390a may be electrically connected to correction electrode 390f. A first DC voltage source 394 may connect electrode 390a to electrode 390b, and second DC voltage source 396 may connect correction electrode 390c and 390d. The DC offset may be selected to electrostatically levitate outer combs 340a-340d and thereby cancel the quadrature error.

Referring to FIG. 19, a portion of substrate 304 beneath teeth 344 and 392 may be an n+ diffused region to provide a control pad electrode 398. The control pad electrode 398 is electrically connected to proof mass 302. By applying a generally positive voltage to teeth 392 and a generally negative voltage to teeth 344 and control pad electrode 398, the electric field (shown by field lines 399) generates an upward force F_z on teeth 344.

Returning to FIG. 17A, the correction electrodes 390a and 390f generate an upward force on the teeth on the left side of the rotor which is stronger than the upward force on the teeth on the right side of the rotor

generated by electrodes 390b and 390e. This force imbalance creates a balancing torque which tends to rotate the rotor so that, absent the Coriolis force, it vibrates solely in the X-Y plane. Because the quadrature error results in a linear displacement, the balancing forces need to be proportional to the position of the proof mass about the Z-axis. The balancing torque F_z is proportional to the overlapping area between teeth 344 and teeth 392. Because the overlapping area between teeth 344 and teeth 392 is directly proportional to the angular position of rotor 316, the balancing torque will also be proportional to the angular position of the rotor.

Referring to FIG. 20, another embodiment of dual-axis gyroscopic sensor 300' includes a modified quadrature correction system 314'. In quadrature correction system 314', four generally rectangular or wedge-shaped plates 340a'-340d' are connected to outer edge 326 of rotor 316. Two fixed electrode pads 390a' and 390b' are disposed on substrate 304 beneath each plate. The fixed electrode pads 390a' and 390b' may be formed of n+ diffused regions in the substrate. A DC offset voltage may be applied between each pair of electrode pads to correct the quadrature error. For example, a positive offset voltage may be applied so that the voltage of electrode pad 390b' is higher than the voltage of electrode pad 390a'. As rotor 316 rotates counter-clockwise and the plate 340a' moves rightwards, more of the plate will overlap electrode pad 390b', and thus the right side of the plate will be more attracted to the substrate than the left side of the plate. This will generate a torque which tends to rotate rotor 316 about the X-axis. The dual-axis gyroscopic sensor 300'

otherwise functions in a manner similar to dual-axis gyroscopic sensor 300.

Referring to FIG. 21, in a gyroscopic sensor 400 the drive system, the sensing system, and the quadrature correction system use a single set of electrodes. Gyroscopic sensor 400 includes a proof mass 402 connected to a substrate 404 by a flexible suspension 406. A plurality of opposing electrode fingers 410a and 410b (only two opposing fingers are shown) project from proof mass 402 along the X-axis. Each electrode finger 410a is flanked by respective stationary electrode fingers 412a and 414a. Similarly, each electrode finger 410b is flanked by stationary electrode fingers 412b and 414b.

To sense the position of the proof mass along the Y-axis, a voltage source 420 applies a high-frequency (e.g., one megahertz) AC voltage between upper electrode fingers 412a, 412b and lower electrode fingers 414a, 414b. Proof mass 402 is electrically connected to an integrator 422. The output of integrator 422 provides a position signal.

To drive the proof mass along the X-axis, a voltage-controlled oscillator 426 is connected to apply an AC voltage with a frequency ω between the opposing electrode fingers 412a, 414a and 412b, 414b. The output of integrator 422 is applied to a phase-sensing circuit 428, and the output of phase-sensing circuit 428 controls the voltage-controlled oscillator 426.

The output voltage V_{out} from integrator 422 is

$$V_{out} = \frac{Q_{struct}}{C_I} \qquad (20)$$

where Q_{struct} is the charge on the proof mass and C_I is the capacitance of integrator 422. Q_{struct} is given by the equation:

$$Q_{struct} = \frac{dC_s}{dy}\Delta y V_{sense} + \Delta C_x(t)\, V_F(t) \qquad (21)$$

where $V_F(t)$ is AC portion of the forcing voltage, $C_x(t)$ is the changing capacitance on the forcing electrodes as the structure displaces along the X-axis, and V_{sense} is the sense voltage applied by voltage source 420. Combining Equations 20 and 21 yields:

$$V_{out} = \frac{\Delta C_x(t)\, V_F(t)}{C_I} + other\ terms \qquad (22)$$

If the forcing voltage $V_F(t)$ is $V_F \sin(\omega t)$ then the resulting displacement $x(t)$ is given by the following equation:

$$x(t) = X_0(\omega, \omega_x)\sin(\omega t + \phi(\omega, \omega_x)) \qquad (23)$$

where ω is the drive frequency, ω_x is the driven mode resonance frequency, $X_0(\omega, \omega_x)$ is the amplitude, and $\phi(\omega, \omega_x)$ is a phase difference. Because $\Delta Cx(t)$ is proportional to $x(t)$,

$$V_{out} = \frac{\Delta C_x(\omega, \omega_x)}{C_I}\sin(\omega t + \phi(\omega, \omega_x))\sin(\omega t) \qquad (24)$$

and therefore

$$V_{out} = \frac{\Delta C_x(\omega, \omega_x)}{2C_I}[\cos(\phi(\omega, \omega_x)) - \cos(2\omega t + \phi(\omega, \omega_x))] \qquad (25)$$

When the drive frequency ω is equal to the resonant frequency ω_x, the phase ϕ will be 90°. Because

the $\cos(\phi(\omega,\omega_x))$ term of Equation 25 produces a DC offset, phase-sensing circuit 428 can drive the frequency ω of voltage-controlled oscillator 426 to the resonant frequency ω_x by sensing when there is no DC offset. Thus, the drive voltage will remain phase locked with the position of the proof mass.

Quadrature error correction may be accomplished in gyroscopic sensor 400 by applying a DC voltage between electrode fingers 412a and 414a and an equal but opposite DC voltage between electrode fingers 412b and 414b.

Referring to FIG. 22, a micromachined gyroscopic sensor 500 may be fabricated using high-aspect-ratio single-crystal-silicon micromachining techniques to produce an extremely thick device. Gyroscopic sensor 500 includes a vibratory structure 502 connected to a rigid frame or substrate 504 at anchor points 511. Structure 502 is configured to vibrate in a plane parallel to a surface 505 of the substrate. As such, a gap of about 0.5 to 4.0 microns, such as about 1.0 microns, separates the vibratory structure from surface 505.

Structure 502 is generally H-shaped, and includes a proof mass portion 506 and a flexible suspension portion 508. The suspension portion includes two parallel crossbeams 516 and four parallel flexures 510 positioned generally along the X-axis. One end of each flexure is connected to anchor 511 which connects structure 502 to the substrate, and the other end of each flexure is connected to one of crossbeams 516. The total length of one crossbeam 516 and two flexures 510 may be about 200 to 1500 microns in length, preferably about 1250 microns.

Proof mass portion 506 includes two crossbars 512 connected to two beams 514 to provide a generally square

arrangement. Three additional crossbars 512 are also connected between beams 514. A plurality of electrode teeth or fingers project along the X-axis from the crossbars 512. Four additional flexures 518 may connect flexures 510 to proof mass portion 506.

Structure 502 may be formed of single-crystal silicon. The structure 502 may have a thickness T of at least 25 microns, and it is advantageous for the thickness T to be at least 50 microns. The thickness may be between about 50 and 100 microns, but for some applications the thickness may be 250 microns. The flexures of the structure may have a width W_F of about two to five microns. The aspect ratio, i.e., the ratio of width to thickness, of the flexures should be greater than 10:1, and it is advantageous for the aspect ratio to be greater than 20:1. The aspect ratio may even be 50:1 or more. The beams and crossbars of the proof mass portion may have a width W_B of about five to ten microns. The total mass of structure 502 may be about 10 to 50 micrograms.

The suspension portion 508 is designed to be flexible along the X-axis and Y-axis and rigid to other modes of vibration. In particular, the high-aspect ratio of the flexures results in a structure which is very rigid to torsion and Z-axis acceleration.

Referring to FIG. 23, the micromachined gyroscopic sensor 500 includes four major electronic elements: a drive system 520 used to sustain oscillation of structure 502 along the X-axis, a sensing system 540 used both to detect deflections of structure 502 along the Y-axis, a sense tuning system 560 used to adjust the resonant frequency of structure 502 along the Y-axis, and a

quadrature correction system 580 used to apply electrostatic forces to cancel quadrature error.

As shown in FIGS. 15 and 16, the drive system 520 includes two opposing driving electrode combs 522a and 522b and two feedback electrode combs 524a and 524b, all connected to substrate 504. Each driving electrode comb and feedback electrode comb includes a plurality of electrode teeth or fingers 526 which project along the drive axis and which are interdigited with electrode teeth or fingers 528 which project from structure 502. Electrode teeth 526 and 528 may have a length L of about fifteen microns, and a width W_E of about two to six microns. Electrode teeth 526 may be separated from electrode teeth 528 by a gap of about 2.5 microns. Electrode teeth 526 and 528 may be formed from the same layer of single-crystal silicon and have a thickness of about 100 microns.

The feedback electrodes combs 524a and 524b are electrically connected to the positive and negative inputs of a trans-resistance amplifier 530. The driving electrode combs 522a and 522b are connected to the positive and negative outputs, respectively, of the transresistance amplifier and to a phase-locked loop circuit 532. At least one of the outputs from transresistance amplifier 530 may be mixed with a velocity signal from phase-locked loop 532 by a mixer 534. The output of mixer 534 is then used to modulate transresistance amplifier 530 to provide an automatic gain control circuit to control the oscillation amplitude of structure 502.

The sensing system 540 includes an opposing pair of sense electrode combs, including left sense electrode combs 542a and 542b, and right sense electrode combs 544a

and 544b. The left sense electrode combs 542a, 542b include a plurality of "left" electrode teeth 546, and the right sense electrode combs 544a, 544b include a plurality of "right" electrode teeth 548. The electrode teeth 546 and 548 are interdigited with electrode teeth 550 which project from structure 502 such that each electrode tooth 550 is disposed between one left tooth 546 and one right tooth 548.

Electrode teeth 546, 548 and 550 may have a length L of about fifteen microns, and width W_E of about two to six microns. Electrode teeth 546, 548 and 550 have a thickness of at least 25 microns, and the thickness may be between about 50 and 100 microns. The aspect ratio of the electrode teeth should be at least about 5:1. The aspect ratio may be at least 10:1, and it may be between about 10:1 and 20:1. Electrode teeth 550 may be separated from electrode teeth 546 and 548 by a gap having a width W_G between about 0.5 and 4.0 microns, such as 2.5 microns. The aspect ratio of the gap should be at least 10:1, and it may be greater than 20:1 or even greater than 50:1. Electrode teeth 546, 548 and 550 may be formed from the same layer of single-crystal silicon in the same fabrication step so that the teeth are coplanar.

A first sense voltage source 552 applies an AC voltage to left sense electrode combs 542a and 542b. A second sense voltage source 554 applies an AC voltage, 180° out of phase with the first sense voltage, to right sense electrode combs 544a and 544b. The sense voltage sources may generate AC signals having a maximum voltage of about 0.1 to 5.0 volts and a frequency of about 0.1 to 5.0 megahertz. The AC signals may have a voltage amplitude of one volt and a frequency of one megahertz.

To measure the Coriolis signal Ω_z, structure 502 is electrically connected to an integrator 556, and the output of integrator 556 is amplified by an AC amplifier 558. The signal from one of the sense voltage sources is mixed with a position signal from phase-locked loop 532 by a mixer 536. The output of mixer 536 is then mixed with the output of amplifier 558 by a mixer 538 to generate the Coriolis signal.

Tuning of the Y-axis resonant frequency may be accomplished sense tuning system 560 applying a DC bias voltage between a set of inner tuning electrodes 562 and outer tuning electrodes 564. Electrodes 566 project from structure 502 and are interdigited with the inner tuning electrodes 562 and outer tuning electrodes 564. A tuning voltage source 568 applies a bias voltage $V_{\Delta fy}$ between inner tuning electrodes 562 and outer tuning electrodes 564. Alternately, the Y-axis resonant frequency could be tuned by applying a DC bias between the vibratory structure and the tuning electrodes.

Quadrature error cancellation is accomplished by applying a voltage between diagonal pairs of electrodes. The quadrature error correction system 580 includes a lower left electrode 582a, an upper left electrode 582b, a lower right electrode 584a, and an upper right electrode 584b. Lower left electrode 582a is connected to upper right electrode 584b, and upper left electrode 582b is connected to lower right electrode 584a. A quadrature correction voltage source 586 applies a bias voltage $2V_{Quad}$ between the electrode pairs 582a, 584b and 582b, 584a. The bias voltage creates a balancing force which is proportional to the position of the proof mass along the X-axis. This bias voltage may be determined

experimentally (as shown in FIG. 13) and may be in the range of 1 mV to 100 mV.

In addition, quadrature error correction system 580 may include a feedback loop to automatically adjust the bias voltage. A velocity signal from phase-locked loop 532 may be mixed with a signal from one of the sense voltage sources by a mixer 590. The output of mixer 590 may be mixed with the output of amplifier 558 by a mixer 592. The output of mixer 592 may be used to control the voltage source 586.

Assuming that the mass M of structure 502 is 36 micrograms, the drive and sense frequencies ω_x and ω_y are each 63 kHz, the quality factor Q for single-crystal silicon is 200,000 (about three to four times higher than that of polysilicon), and the amplitude X_0 of the drive mode is five microns, then one may calculate from Equation 16 that, at room temperature, the Brownian noise Ω_{nB} for a bandwidth (BW) of 60 Hz is about 2 deg/hr.

The electronic noise floor is determined by the thermal noise level in charge integrator 556. Where the sense frequency ω_y is electrostatically tuned to the drive frequency ω_x plus an offset frequency $\Delta\omega$, the electronic noise Ω_{nE} may be calculated from the equation:

$$\Omega_{nE} = 2\frac{g_0\Delta\omega}{X_0 V_S}\sqrt{\frac{32}{3\pi}\left(\frac{k_B T}{C_S}\right)\frac{1}{f_T}\left(\left(1+\frac{C_P}{C_S}\right)BW\right.} \qquad (26)$$

where g_0 is the sense-capacitor gap width, X_0 is the oscillation amplitude, V_S is the sense voltage, k_B is Boltzmann's constant, T is the temperature, C_S is the sense capacitance, C_P is the parasitic capacitance, f_T is the CMOS transition frequency, and BW is the bandwidth.

Assuming that the sense-capacitor gap g_0 is 2.5 microns, the sense voltage V_S is 1 V, C_S is the sense capacitance C_S is 1.25 pF, the parasitic capacitance C_P is 0.25 pF, and the CMOS transition frequency f_T is 1 GHz, one may calculate from Equation 18 that a frequency offset $\Delta\omega$ of 2π(175 Hz) is required to make the electronic noise floor equal to 2.5 deg/hr. This degree of tuning is feasible in principle because the measurement bandwidth is about 60 Hz.

By increasing the thickness of electrode teeth 546, 548 and 550, the surface area between the stationary and movable electrodes is increased, resulting in a larger sense capacitance. The larger sense capacitance reduces electronic noise. Similarly, the thicker structure is more massive and thus less subject to Brownian motion. In short, a gyroscopic sensor using high-aspect-ratio single-crystal silicon structures may be about one-hundred times more sensitive than a gyroscopic sensor using structures formed of thin polysilicon layers.

Fabrication of gyroscopic sensor 500 includes six basic steps: handle wafer processing, device wafer processing, bonding, CMOS processing of the bonded structure, etching to form the vibratory structure and stationary electrodes, and capping.

Referring to FIG. 24A, processing of a bottom substrate 600 may begin with a handle wafer 602, which may be a single-crystalline silicon substrate. Handle wafer 602 is oxidized to form an oxide layer 604, and a polysilicon layer 606 is deposited on oxide layer 604. Polysilicon layer 606 is then doped, polished and patterned to form the interconnects for the electrically isolated electrodes 522a, 522b, 524a, 524b, 542a, 542b,

544a, 544b, 562, 564, 582a and 584b, and 582b and 584a, of the gyroscopic sensor.

Referring to FIG. 24B, processing of a top substrate 610 may begin with a device wafer such as a silicon-on-insulator (SOI) substrate. The device wafer includes an oxide layer 616 sandwiched between two single-crystal silicon layers 614 and 618. A shallow trench 620 is formed in a surface 622 of single-crystal silicon layer, except in regions 624. Regions 624 will form anchors 511 connecting vibratory structure 502 to substrate 504. Trench 620 may be formed by deposition of a photoresist mask, etching of the exposed portions of single-crystal silicon layer 614, and removal of the mask. Alternately, trench 620 may be formed by mechanical thinning.

The thickness of single-crystal silicon layer 614 will define the thickness of vibratory structure 502, and the depth of trench 620 will define the spacing between the vibratory structure and the substrate. Preferably, single-crystal silicon layer 614 is about 100 microns thick, and trench 620 is about one micron deep.

Referring to FIG. 24C, bottom substrate 600 and top substrate 610 are aligned with surface 622 of top substrate 610 abutting the patterned polysilicon layer 606 of bottom substrate 600. The top and bottom substrates are bonded so that trench 620 forms a sealed cavity 626 between the two substrates. Then, referring to FIG. 24D, top substrate 610 is thinned by etching or mechanical removal of single-crystal silicon layer 618 to expose oxide layer 616, and oxide layer 616 is stripped. At this point, the bonded assembly is ready for standard CMOS processing. Because sealed cavity 626 is completely internal, the bonded assembly appears as an unprocessed

silicon wafer and may processed with conventional techniques.

Referring to FIG. 24E, the integrated circuitry of gyroscopic sensor 500 is fabricated on an exposed surface 630 of single-crystal silicon layer 614 in device regions 632. Following circuit fabrication, a thermocompression bond layer 634 is deposited and patterned. The bond layer 634 may be a conductive metal, such as gold.

Referring to FIG. 24F, the structures of the gyroscopic sensor are formed in single-crystal silicon layer 614. A photoresist mask is deposited over bond layer 634 and exposed surface 630, and the photoresist mask is patterned to define the gaps between the vibratory structure 502 and the stationary electrodes (not shown in this cross-sectional view). The single-crystal silicon layer 614 is etched using inductively-coupled plasma based deep reactive ion etching until cavity 626 is exposed. The etching step forms trenches 636 which create the free-standing vibratory structure and the various electrode structures of the gyroscopic sensor. Following the reactive ion etching, an oxygen plasma may be used to remove the photoresist mask, and the assembly may undergo a UV-ozone clean.

Finally, referring to FIG. 24G, a capping wafer 640 is aligned and bonded to top substrate 610. Capping wafer 640 may be glass or oxidized silicon. An underside 642 of the capping wafer may include a patterned thermocompression bond layer 644. Bond layer 634 may be aligned with bond layer 644, and the thermocompression bond may be formed by the application of a pressure of approximately 20 psi and a temperature of about 300-350°C for several minutes. The capping wafer may also include

an etched hole 646 that permits access to bonding pads 648 in device regions 632.

The present invention has been described in terms of a preferred embodiment. The invention, however, is not limited to the embodiment depicted and described. Rather, the scope of the invention is defined by the appended claims.

What is claimed is:

1. A microfabricated structure comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers, coplanar with said first plurality of electrode fingers, connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said first third plurality of electrode fingers being coplanar with said first and second plurality of electrode fingers and projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers.

2. The structure of claim 1 further comprising a voltage source to apply a voltage between said second and third plurality of electrode fingers.

3. The structure of claim 1 further comprising

a fourth plurality of electrode fingers, coplanar with said first, second and third plurality of electrode

fingers, projecting from said mass along said first axis, and

a fifth plurality of electrode fingers connected to said substrate but electrically isolated from said second and third plurality of electrode fingers, said fourth and fifth plurality of electrode fingers interdigitated.

4. The structure of claim 3 wherein each of said first plurality of electrode fingers has a first length and each of said fourth plurality of electrode fingers has a second length.

5. The structure of claim 4 wherein said first length is greater than said second length.

6. A microfabricated structure comprising:

a substrate; and

a suspension system to permit a mass to vibrate in a plane parallel to a surface of said substrate, said suspension system including,

first and second substantially parallel beams, each of said first and second beams anchored at both ends to said substrate, and

third and fourth substantially parallel beams, one end of each of said third and fourth beams connected to said first beam and another end connected to said second beam.

7. The structure of claim 6 further comprising a plurality of fingers projecting along an axis substantially parallel to said first and second beams.

8. The structure of claim 6 further comprising

a fifth and a sixth beam, one end of each of said fifth beam and sixth beams connected to said third beam and another end connected to said fourth beam, and

a seventh beam, one end of said seventh beam connected to said fifth beam and another end connected to said sixth beam.

9. The structure of claim 8 further comprising a plurality of fingers projecting from said seventh beam along an axis substantially parallel to said first and second beams.

10. The structure of claim 6 wherein sections of said first and second beams located between said third and fourth beams are substantially rigid to prevent rotation of said mass.

11. A sensor comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said third plurality of electrode fingers projecting substantially along said first axis, said second and third pluralities

of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers;

a position sensor to mesure a deflection of said mass in said plane; and

a voltage source for applying a first DC voltage between said second and third pluralities of electrode fingers to cause said mass to vibrate, absent a Coriolis force, more precisely along said first axis.

12. The sensor of claim 11 further including,

a fourth plurality of electrode fingers projecting from said mass along a first axis in said plane and positioned opposing said first plurality of electrode fingers;

a fifth plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a sixth plurality of electrode fingers connected to said substrate but electrically isolated from said fifth plurality of electrode fingers, said sixth plurality of electrode fingers projecting substantially along said first axis, said fifth and sixth plurality of electrode fingers interdigitated with said third plurality of electrode fingers such that each of said fourth plurality of electrode fingers is adjacent to one of said fifth plurality of electrode fingers and one of said sixth plurality of electrode fingers.

13. The sensor of claim 12 further comprising a second voltage source for applying a second DC voltage between

said fifth and sixth plurality of electrode fingers to cause said mass to vibrate, absent a Coriolis force, more precisely along said first axis.

14. The sensor of claim 13 wherein said second DC voltage is substantially equal in magnitude but opposite in sign to said first DC voltage.

15. The sensor of claim 13 wherein said first plurality of electrode fingers is electrically coupled to said second plurality of electrode fingers.

16. The sensor of claim 13 further comprising a voltage source for applying a third DC voltage between said first and third pluralities of electrode fingers and said second, third, fifth and sixth pluralities of electrode fingers to adjust the resonant frequency of vibrations of said mass along a second axis in said plane perpendicular to said first axis.

17. The sensor of claim 11 wherein the position sensor measures the deflection of said mass along a second axis substantially perpendicular to said first axis and rotation of said mass about a Z-axis perpendicular to said surface and vibration of said mass along said first axis generates a Coriolis force to deflect said mass along said second axis, and wherein the sensor further comprises a signal processor coupled to an output of said position sensor to generate a signal varying with the rate of rotation of said mass about the Z-axis.

18. The sensor of claim 17 further comprising a voltage source for applying an AC voltage between said second and third plurality of electrode fingers.

19. The sensor of claim 18 wherein a voltage is applied between said second and third pluralities of electrode fingers to form a capacitive bridge with said first plurality of electrodes, and said position sensor is coupled to said first plurality of electrodes to detect changes in capacitance when said mass is deflected along said second axis.

20. A sensor comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a first plurality of electrode fingers projecting from said mass along a first axis in said plane;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate but electrically isolated from said second plurality of electrode fingers, said first third plurality of electrode fingers projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers; and

a voltage source for applying a DC voltage between said first plurality of electrode fingers and said second and third plurality of electrode fingers to adjust the resonant frequency of vibrations of said mass along a second axis in said plane perpendicular to said first axis.

21. A microfabricated gyroscopic sensor for sensing rotation about a Z-axis, comprising:

a substrate;

a mass connected to said substrate by a suspension system to vibrate in a plane parallel to a surface of said substrate;

a drive system to cause said mass to vibrate substantially along a first axis in said plane;

a first plurality of electrode fingers projecting from said mass substantially along said first axis;

a second plurality of electrode fingers connected to said substrate and projecting substantially along said first axis;

a third plurality of electrode fingers connected to said substrate and projecting substantially along said first axis, said second and third plurality of electrode fingers interdigitated with said first plurality of electrode fingers such that each of said first plurality of electrode fingers is adjacent to one of said second plurality of electrode fingers and one of said third plurality of electrode fingers;

a position sensor coupled to said first plurality of electrode fingers for measuring the deflection of said mass along a second axis in said plane perpendicular to said first axis, wherein rotation of said mass about a Z-axis perpendicular to said surface and vibration of said

mass along said first axis generates a Coriolis force to deflect said mass along said second axis; and

a signal processor coupled to an output of said position sensor to generate a signal varying with the rate of rotation of said mass about the Z-axis.

22. The sensor of claim 21 further comprising a voltage source for applying an AC voltage having a first frequency between said second and third plurality of electrode fingers.

23. The sensor of claim 22 wherein a voltage is applied between said second and third pluralities of electrode fingers to form a capacitive bridge with said first plurality of electrodes, and said position sensor is coupled to said first plurality of electrodes to detect changes in capacitance when said mass is deflected along said second axis.

24. The sensor of claim 23 wherein said position sensor further includes an integrator to integrate a signal from said first plurality of electrode fingers.

25. The sensor of claim 24 wherein said drive system generates a signal to cause said mass to oscillate along said first axis at a second frequency.

26. The sensor of claim 25 wherein said drive system said signal.

27. The sensor of claim 25 further including a first mixer to mix the signal from said drive system with a signal from said voltage source.

28. The sensor of claim 27 further including a second mixer to mix a signal from said first mixer with an output signal from said position sensor to produce a position quadrature signal.

29. The sensor of claim 27 further including a second mixer to mix a signal from said first mixer with an output signal from said position sensor to produce a Coriolis signal.

30. The sensor of claim 25 further including a mixer to mix an output signal from said position sensor with a signal from said voltage source to produce a position signal.

31. A microfabricated gyroscopic sensor, comprising:

a substrate;

a mass connected to the substrate by a suspension system;

a drive system to cause the mass to vibrate along a drive axis substantially parallel to a surface of the substrate; and

a position sensor to measure a deflection of the mass along a sense axis substantially parallel to the surface of the substrate, wherein rotation of the mass about an axis of rotation substantially perpendicular to the surface of the substrate and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along the sense axis.

32. The sensor of claim 31 further comprising a processor coupled to an output of the position sensor to

generate a signal varying with the rate of rotation of the mass about the axis of rotation.

33. The sensor of claim 31 wherein the position sensor includes a first sense electrode projecting from the mass, a second sense electrode connected to the substrate and positioned on a first side of the first electrode, and a third sense electrode connected to the substrate and positioned on an opposing second side of the first electrode.

34. The sensor of claim 33 wherein the position sensor senses a change in capacitance between the first electrode and the second and third electrodes.

35. The sensor of claim 33 wherein the first, second and third electrodes are substantially coplanar and each electrode has a longitudinal axis substantially aligned with the drive axis.

36. The sensor of claim 31 wherein the drive system includes a first drive electrode projecting from the mass, a second drive electrode connected to the substrate and positioned on a first side of the first electrode, and a third drive electrode connected to the substrate and positioned on an opposing second side of the first electrode.

37. The sensor of claim 35 wherein the drive system applies an alternating voltage between the between the first electrode and the second and third electrodes.

38. The sensor of claim 33 wherein the first, second and third electrodes are substantially coplanar and each electrode has a longitudinal axis substantially aligned with the drive axis.

39. The sensor of claim 31 further comprising a voltage source to apply a voltage between a plurality of correction electrodes connected to the substrate to cause the mass to vibrate, absent the Coriolis force, more precisely along the drive axis.

40. The sensor of claim 31 further comprising a voltage source to apply a voltage between a first tuning electrode connected to the substrate and a second tuning electrode connected to the mass to adjust a resonant frequency of vibrations of the mass along the sense axis.

41. A microfabricated gyroscopic sensor, comprising:

a substrate;

a mass connected to the substrate by a suspension system;

a drive system to cause the mass to vibrate substantially along a drive axis;

a position sensor to measure a deflection of the mass along a sense axis, wherein rotation of the mass about an axis of rotation and vibration of the mass along the drive axis generates a Coriolis force to deflect the mass along the sense axis; and

a voltage source to apply a voltage between electrodes connected to the substrate to cause the mass to vibrate, absent the Coriolis force, more precisely along the drive axis.

42. The sensor of claim 41 further comprising a processor coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the axis of rotation.

43. The sensor of claim 41 further comprising a second voltage source to apply a second voltage between electrodes connected to the mass and the electrodes connected to the substrate to adjust a resonant frequency of vibrations of the mass along the sense axis.

44. The sensor of claim 41 wherein the position sensor applies an AC voltage between the electrodes connected to the substrate.

45. The sensor of claim 41 wherein the drive axis and sense axis are substantially parallel to a surface of the substrate and the axis of rotation is substantially perpendicular to the surface of the substrate.

46. The sensor of claim 41 further comprising:

a first plurality of electrode fingers projecting from the mass substantially along the drive axis;

a second plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis; and

a third plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis, the second and third pluralities of electrode fingers interdigitated with the first plurality of electrode fingers such that each of the first plurality of electrode fingers is adjacent to one of the second

plurality of electrode fingers and one of the third plurality of electrode fingers.

47. The sensor of claim 46 further comprising:

a fourth plurality of electrode fingers projecting from the mass substantially along the drive axis and positioned opposing the first plurality of electrode fingers;

a fifth plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis and positioned opposing the second plurality of electrode fingers; and

a sixth plurality of electrode fingers connected to the substrate and projecting substantially along the drive axis and positioned opposing the third plurality of electrode fingers, the fifth and sixth pluralities of electrode fingers interdigitated with the fourth plurality of electrode fingers such that each of the fourth plurality of electrode fingers is adjacent to one of the fifth plurality of electrode fingers and one of the sixth plurality of electrode fingers.

48. The sensor of claim 47 wherein the first, second, third, fourth, fifth and sixth pluralities of electrode fingers are substantially co-planar.

49. The sensor of claim 48 wherein the voltage source applies a first DC voltage between the second plurality and the third plurality of electrode fingers and a second DC voltage between the fifth plurality and the sixth plurality of electrode fingers.

50. The sensor of claim 49 wherein the second DC voltage is substantially equal in magnitude and opposite in sign to the first DC voltage.

51. The sensor of claim 21 further comprising a voltage source for applying a DC voltage between the first plurality of electrode fingers and the second and third pluralities of electrode fingers to adjust a resonant frequency of vibrations of the mass along the second axis.

52. The sensor of claim 21 further comprising a voltage source for applying a first DC voltage between the second and third pluralities of electrode fingers to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

53. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an axis of rotation substantially perpendicular to a surface of the substrate;

causing the mass to vibrate substantially along a drive axis substantially parallel to the surface of the substrate, rotation of the mass about the axis of rotation and vibration of the mass along the drive axis generating a Coriolis force to deflect the mass along a sense axis substantially parallel to the surface of the substrate; and

measuring a deflection of the mass along the sense axis.

54. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an axis of rotation;

causing the mass to vibrate substantially along a drive axis, rotation of the mass about the axis of rotation and vibration of the mass along the drive axis generating a Coriolis force to deflect the mass along a sense axis;

measuring a deflection of the mass along the sense axis; and

applying a voltage between electrode fingers connected to the substrate to cause the mass to vibrate, absent a Coriolis force, more precisely along the first axis.

55. A microfabricated gyroscopic sensor for measuring rotation about an input axis, comprising:

a substrate;

a mass;

a suspension system connecting the mass to the substrate;

a drive system to cause the mass to oscillate substantially about a drive axis;

a position sensor to measure a rotation of the mass about a sense axis, wherein rotation of the mass about the input axis and oscillation of the mass about the drive axis generates a Coriolis force to oscillate the mass about the sense axis;

a plurality of electrodes associated with the substrate; and

a voltage source to apply a voltage between the electrodes to cause the mass to oscillate, in the absence the Coriolis force, more precisely about the drive axis.

56. The sensor of claim 55 further comprising a processor coupled to an output of the position sensor to generate a signal varying with the rate of rotation of the mass about the input axis.

57. The sensor of claim 55 further comprising a second voltage source to apply a second voltage between electrodes connected to the mass and the electrodes connected to the substrate to adjust a resonant frequency of oscillations of the mass about the sense axis.

58. The sensor of claim 55 wherein the position sensor applies an AC voltage between the electrodes connected to the substrate.

59. The sensor of claim 55 wherein the drive axis is substantially perpendicular to the surface of the substrate and the input axis and sense axis are substantially parallel to a surface of the substrate.

60. The sensor of claim 59 further comprising:

a first plurality of electrode fingers projecting from the mass;

a second plurality of electrode fingers projecting from the mass;

a third plurality of electrode fingers projecting from the substrate and interdigitated with the first plurality of electrode fingers; and

a fourth plurality of electrode fingers projecting from the substrate and positioned opposing the first plurality of electrode fingers, the fourth plurality of electrode fingers interdigitated with the second plurality of electrode fingers.

61. The sensor of claim 60 further comprising:

a fifth plurality of electrode fingers projecting from the mass;

a sixth plurality of electrode fingers projecting from the mass;

a seventh plurality of electrode fingers projecting from the substrate and interdigitated with the fifth plurality of electrode fingers; and

a eighth plurality of electrode fingers projecting from the substrate and positioned opposing the seventh plurality of electrode fingers, the eighth plurality of electrode fingers interdigitated with the sixth plurality of electrode fingers.

62. The sensor of claim 61 wherein the first, second, third, fourth, fifth, sixth, seventh and eighth pluralities of electrode fingers are substantially co-planar.

63. The sensor of claim 62 wherein the voltage source applies a first DC voltage between the third plurality and the fourth plurality of electrode fingers and a second DC voltage between the seventh plurality and the eighth plurality of electrode fingers.

64. The sensor of claim 63 wherein the second DC voltage is substantially equal in magnitude and opposite in sign to the first DC voltage.

65. The sensor of claim 55 further comprising a first electrode projecting from the mass, a second electrode connected to the substrate and positioned beneath a first portion of the first electrode, and a third electrode connected to the substrate and positioned beneath a second portion of the first electrode.

66. The sensor of claim 55 wherein the mass is substantially ring-shaped.

67. A method of sensing rotation with a gyroscopic sensor including a mass connected to a substrate by a suspension system, comprising:

rotating the mass about an input axis;

causing the mass to oscillate substantially about a drive axis, rotation of the mass about the input axis and oscillation of the mass about the drive axis generating a Coriolis force to oscillate the mass about a sense axis;

measuring an oscillation of the mass about the sense axis; and

applying a voltage between electrodes connected to the substrate to cause the mass to oscillate, in the absence of a Coriolis force, more precisely about the drive axis.

68. A microfabricated gyroscopic sensor, comprising:

a substrate having a first plurality of electrode teeth;

a vibratory structure including a second plurality of electrode teeth and a suspension system connecting the second plurality of electrode teeth to the substrate, the second plurality of electrode teeth interdigited with the first plurality of electrode teeth;

a drive system to cause the vibratory structure to oscillate relative to the substrate; and

a position sensor to measure a deflection of the mass caused by a Coriolis force;

wherein the first and second pluralities of electrode teeth have thicknesses substantially greater than their widths.

69. The sensor of claim 68 wherein the suspension system includes a plurality of flexures having an aspect ratio of at least about 10:1.

70. The sensor of claim 68 wherein the first and second pluralities of electrode teeth have an aspect ratio of at least 5:1.

71. The sensor of claim 68 wherein gaps between the first and second pluralities of electrode teeth have an aspect ratio of at least 10:1.

72. A method of fabricating a gyroscopic sensor, comprising:

forming an insulative layer on a first substrate;

forming a recess in a first surface of a second substrate;

bonding the first surface of the second substrate to the first substrate so that the recess defines an enclosed cavity between the first and second substrates;

forming circuitry for the gyroscopic sensor on a second surface of the second substrate

etching a plurality of trenches in the second substrate from the second surface to the cavity, the plurality of trenches defining a vibratory structure connected to the first substrate.

73. The method of claim 72 wherein the vibratory structure has a thickness of at least 25 microns.

74. The method of claim 72 wherein the recess has a depth of about 1 micron.

75. The method of claim 72 wherein the etching step comprises a deep reactive ion etch.

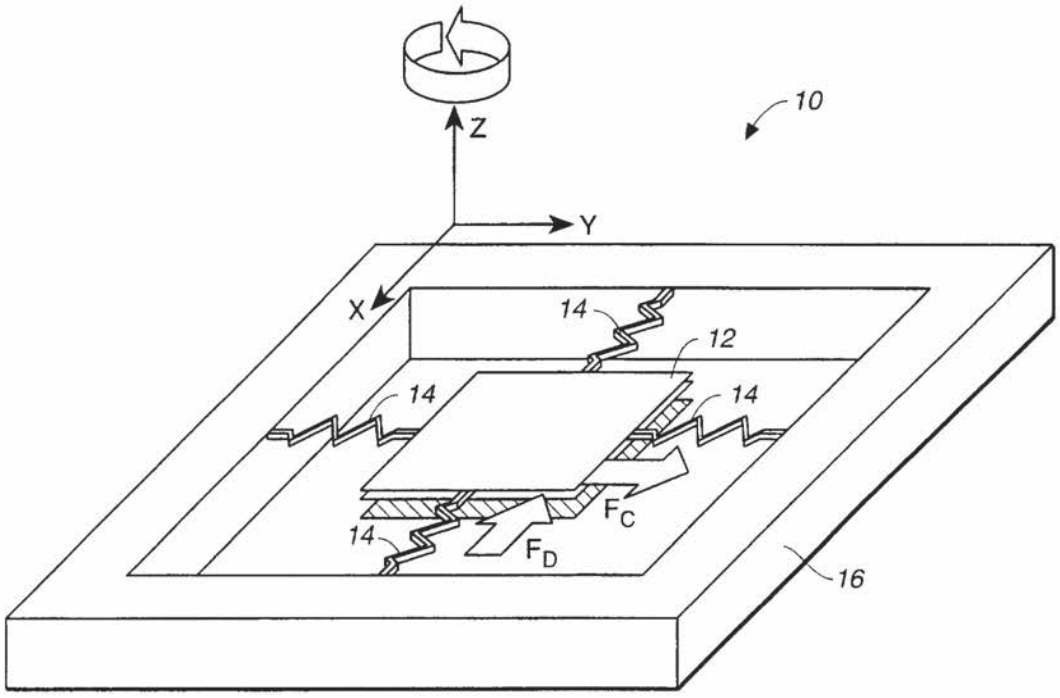


FIG._1

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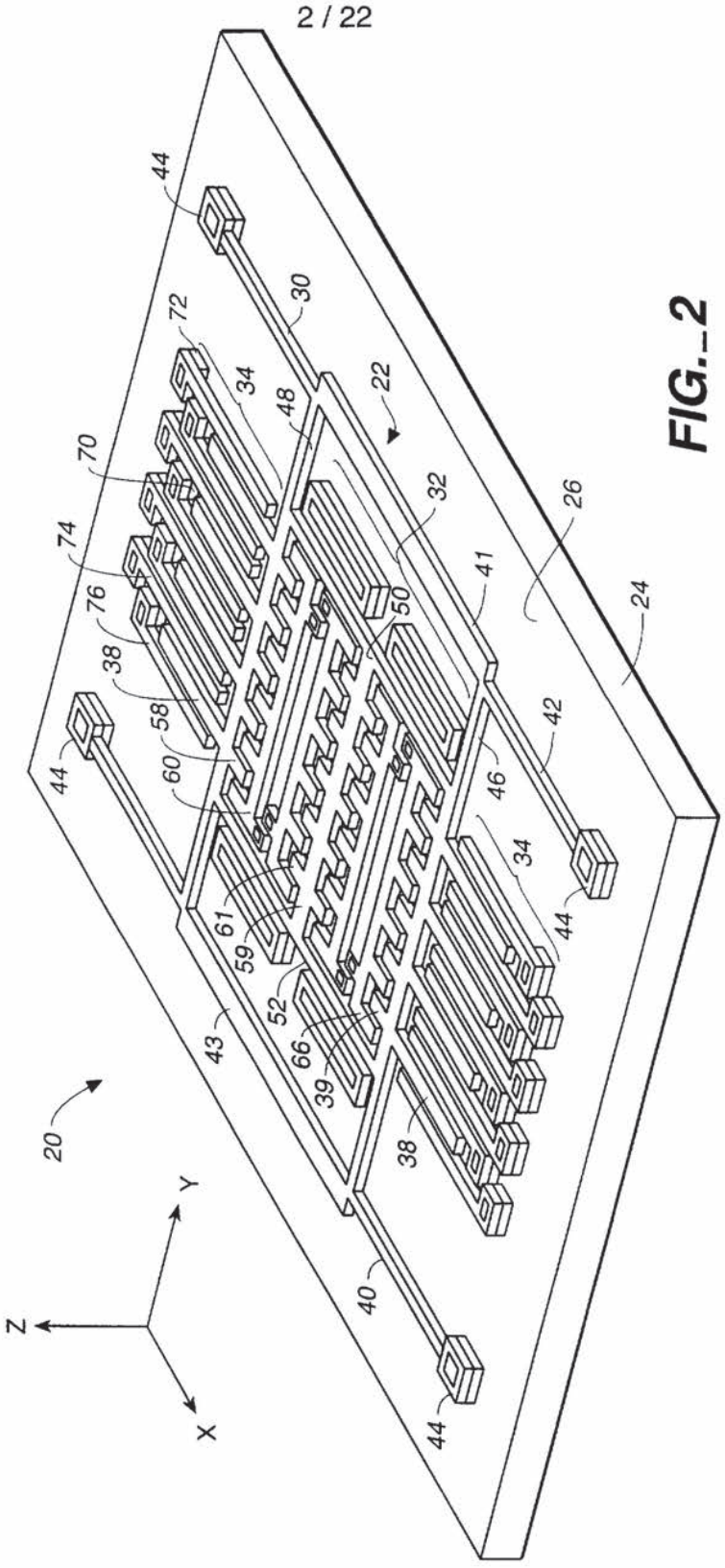


FIG._2

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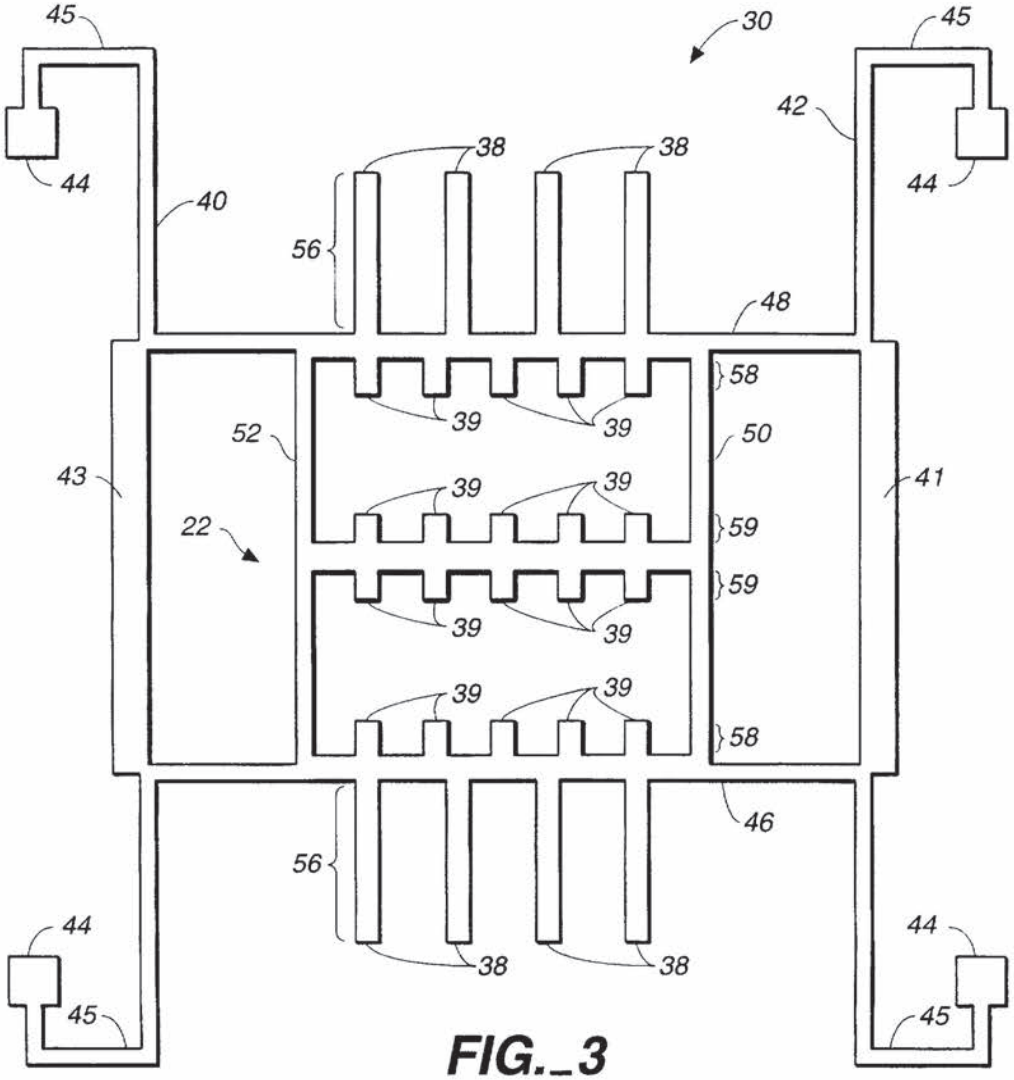


FIG._3

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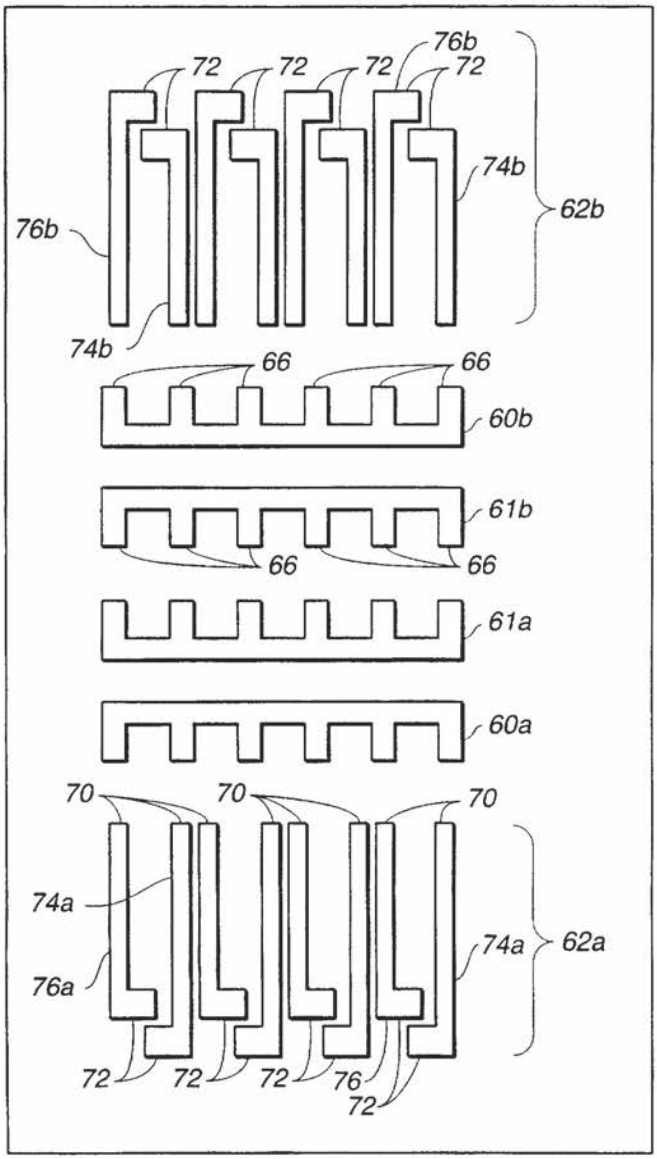


FIG._4

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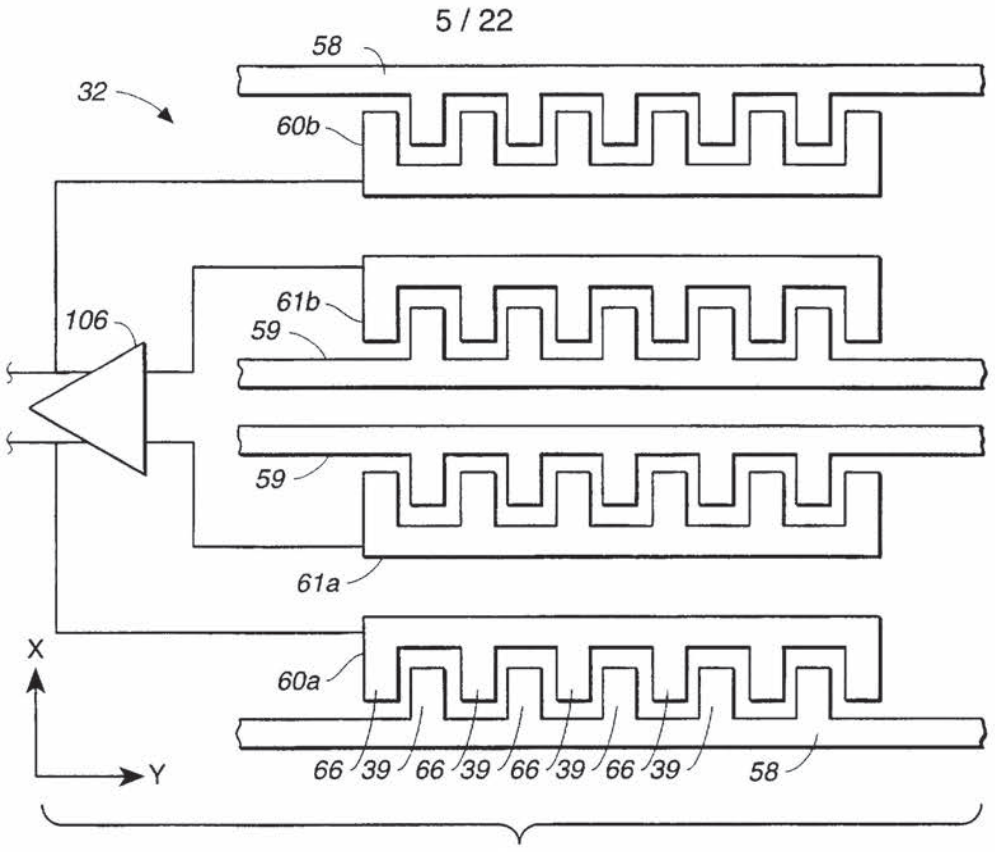


FIG._5

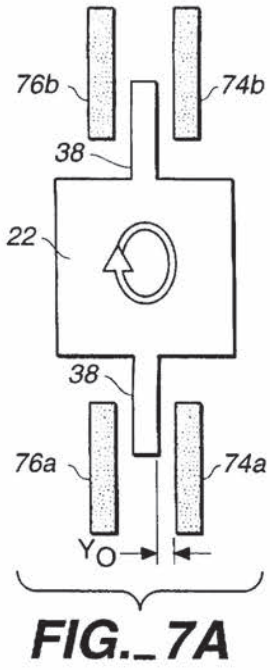


FIG._7A

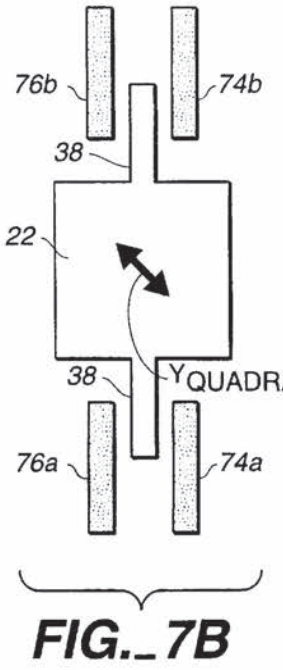


FIG._7B

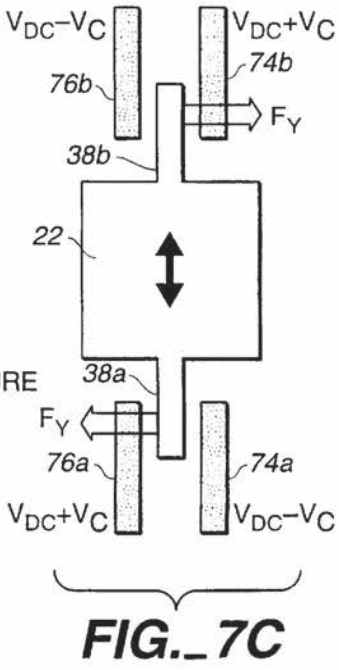


FIG._7C

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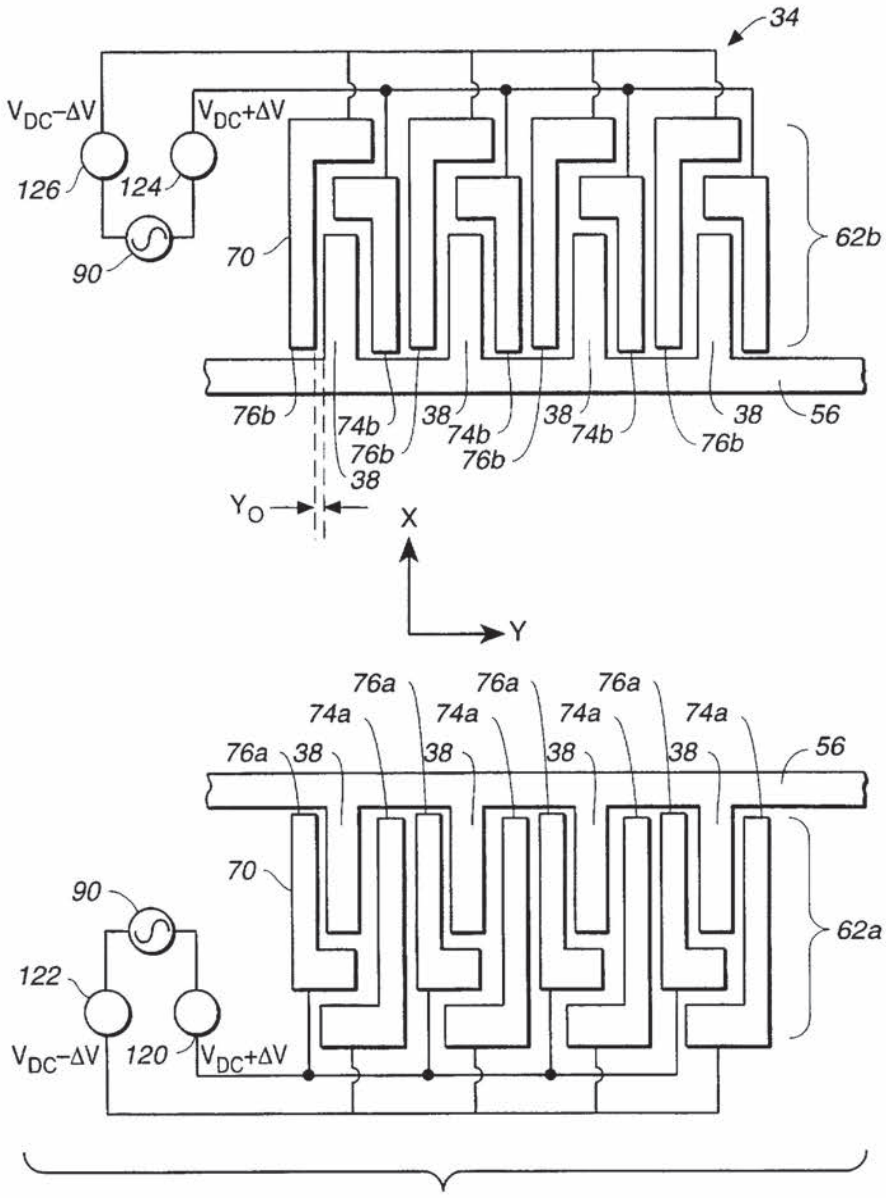


FIG._6

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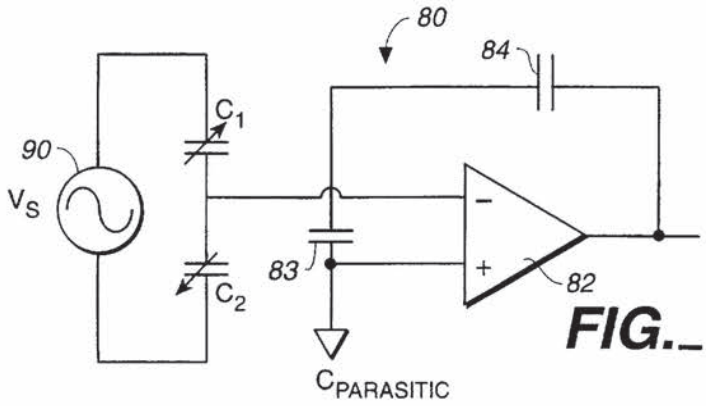


FIG._8A

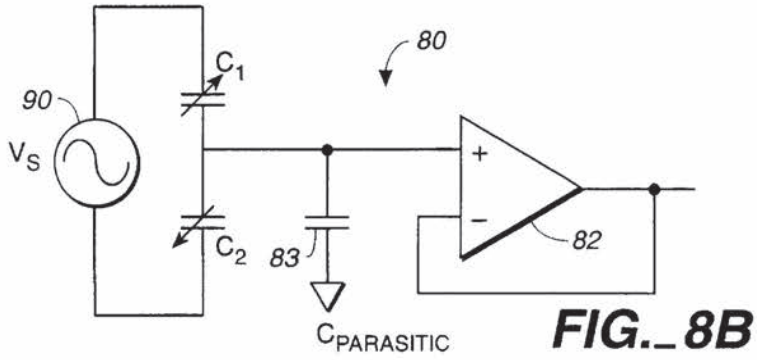


FIG._8B

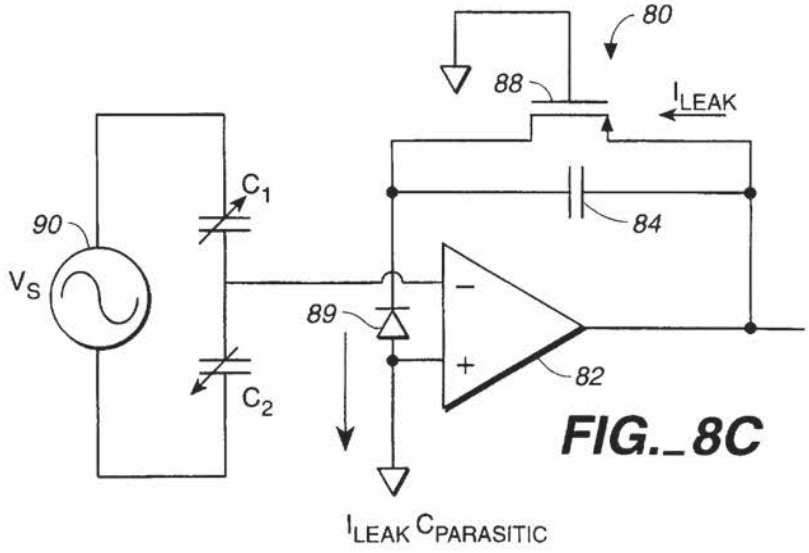


FIG._8C

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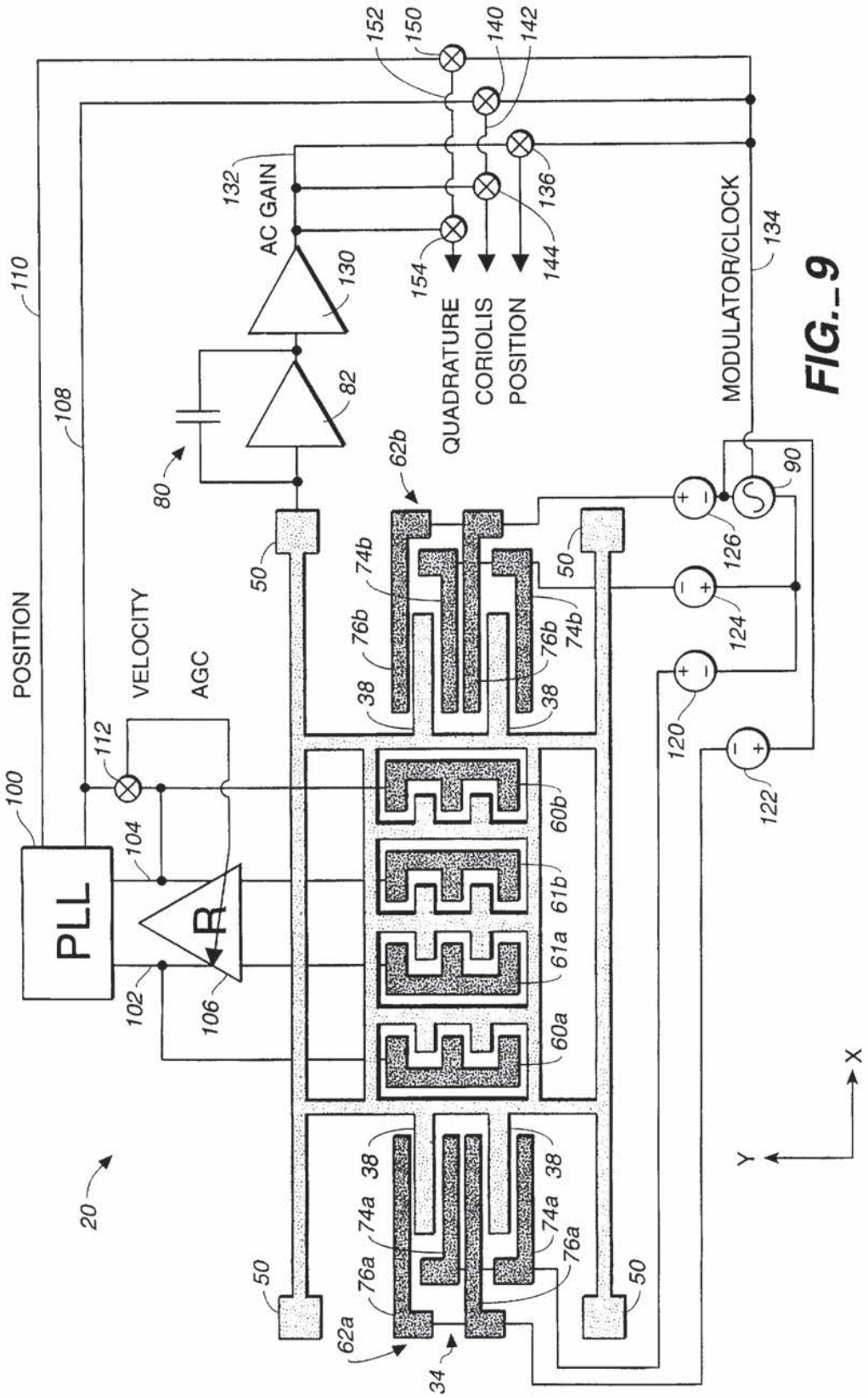


FIG._9

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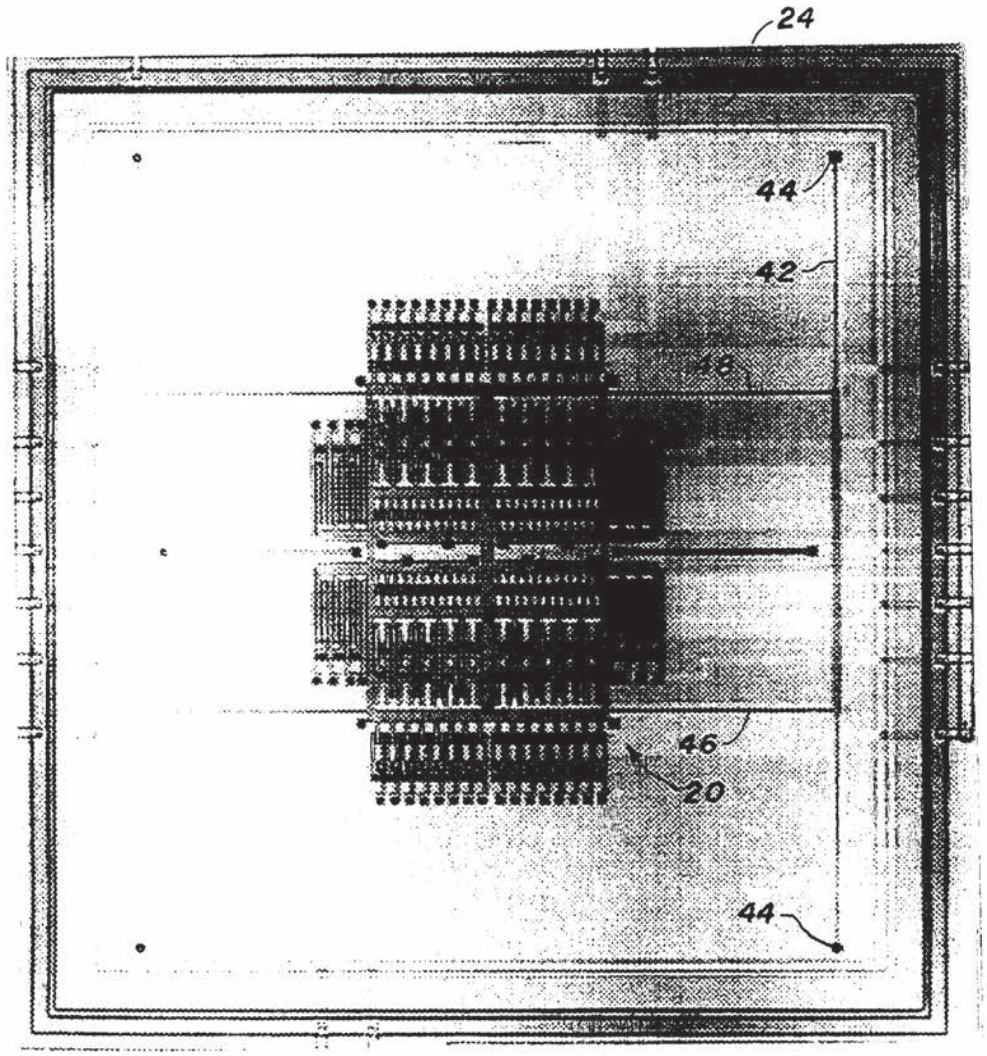


FIG._10

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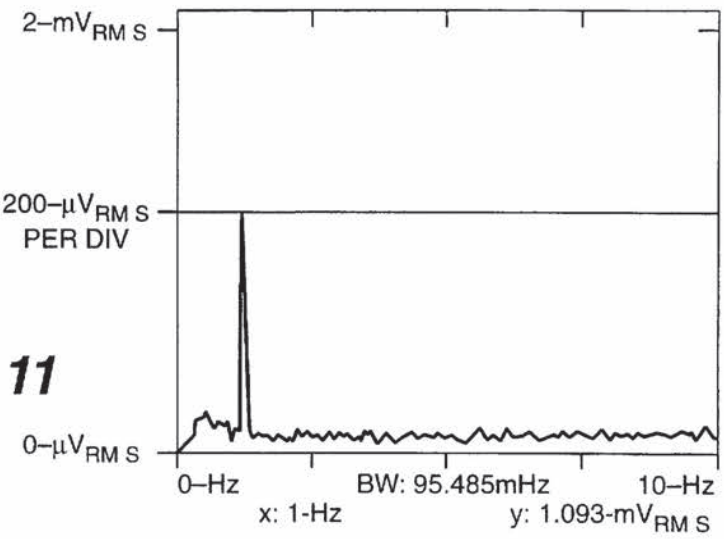


FIG._11

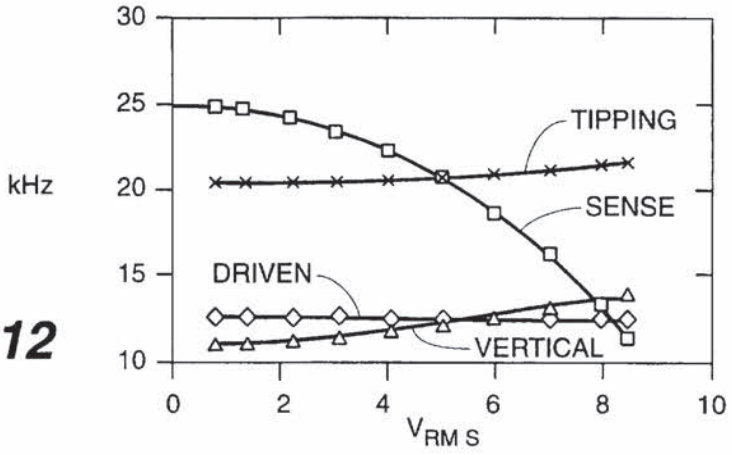


FIG._12

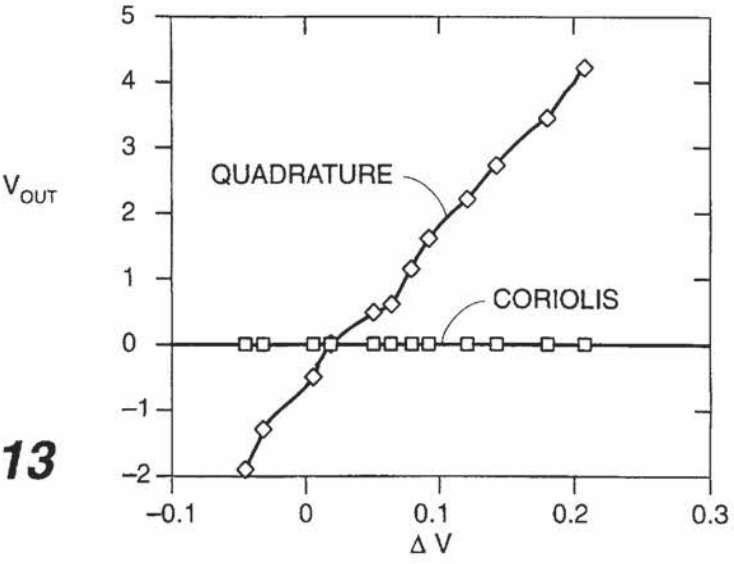


FIG._13

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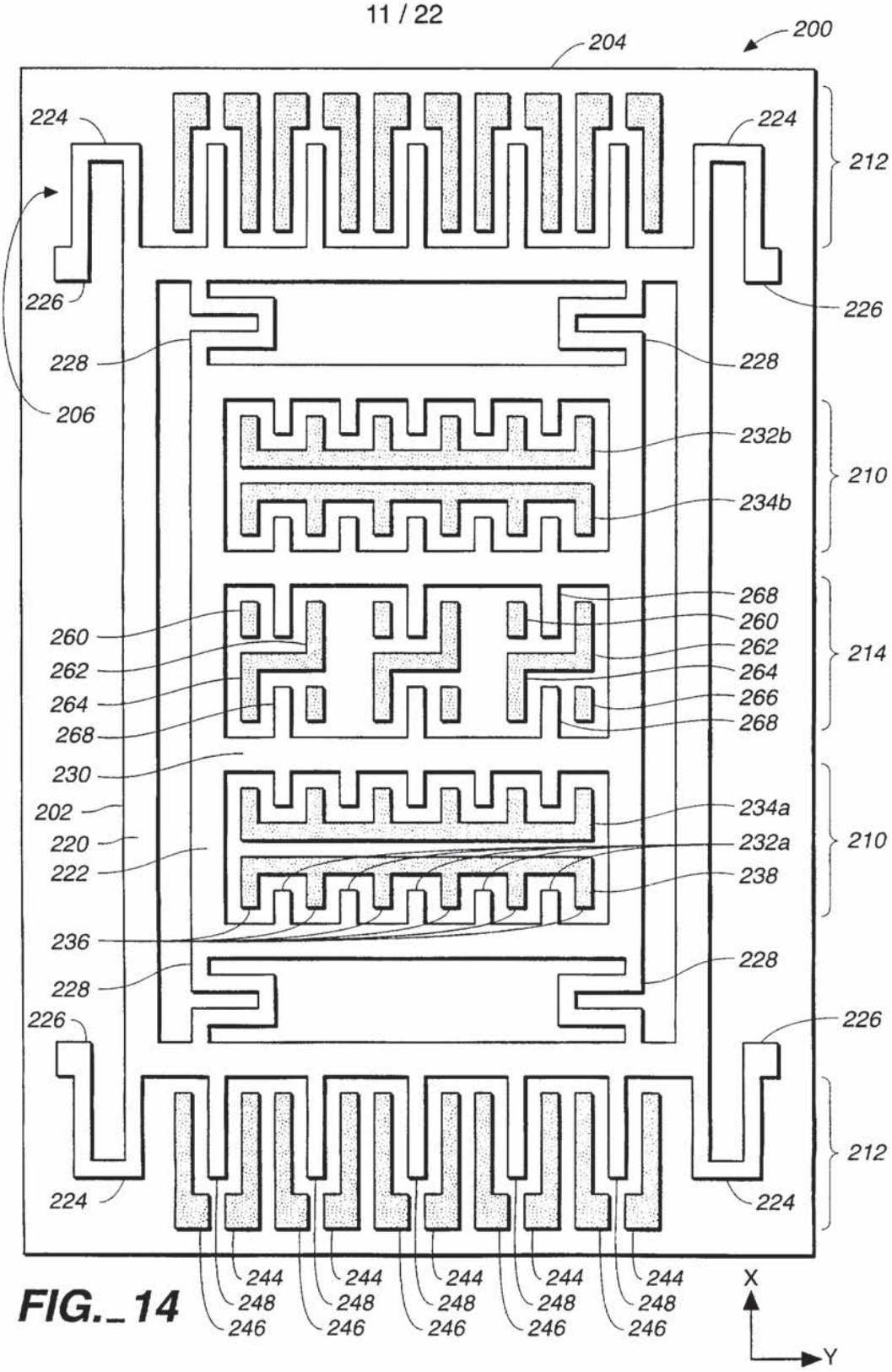
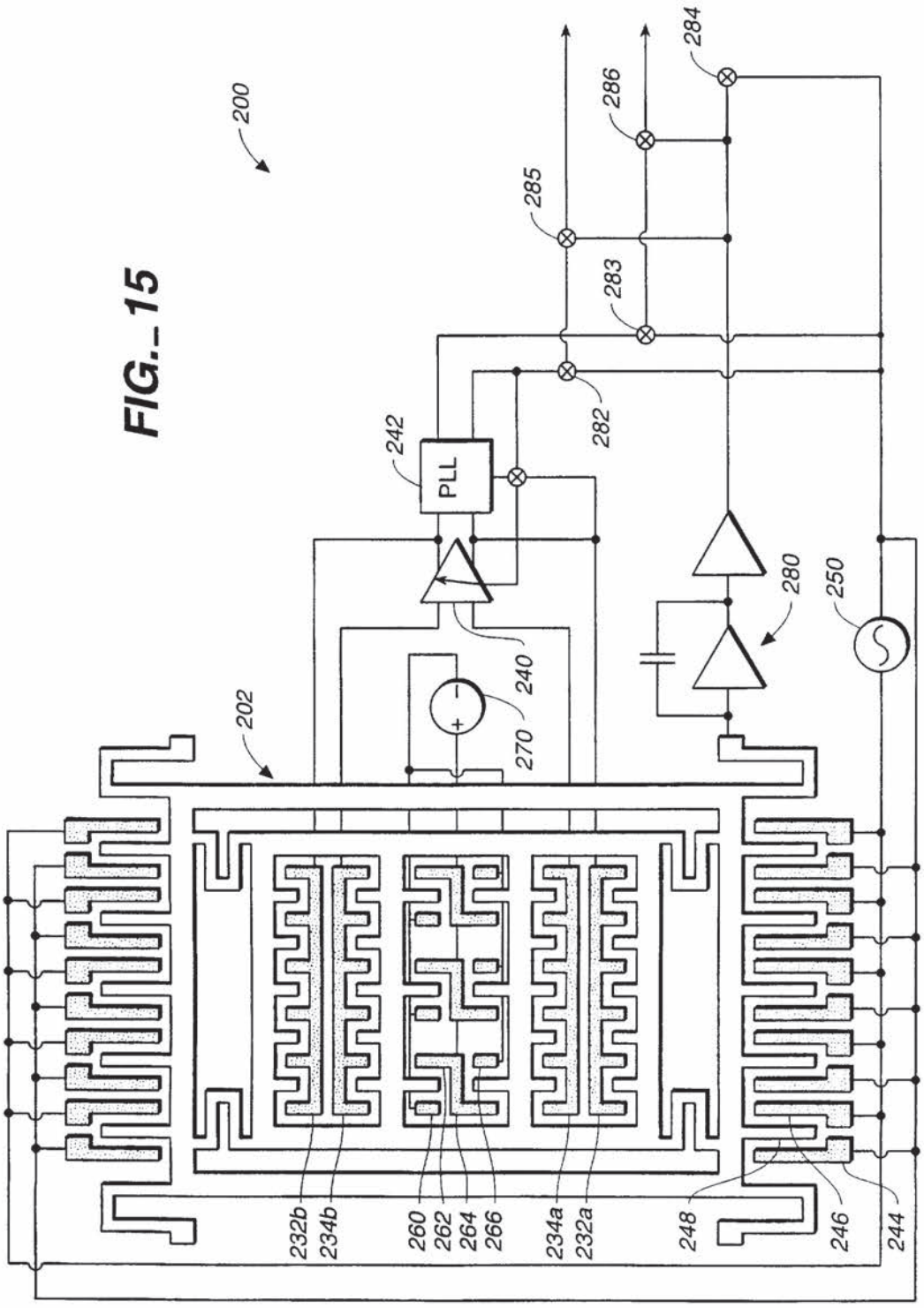


FIG._14

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FIG._15



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FIG._16

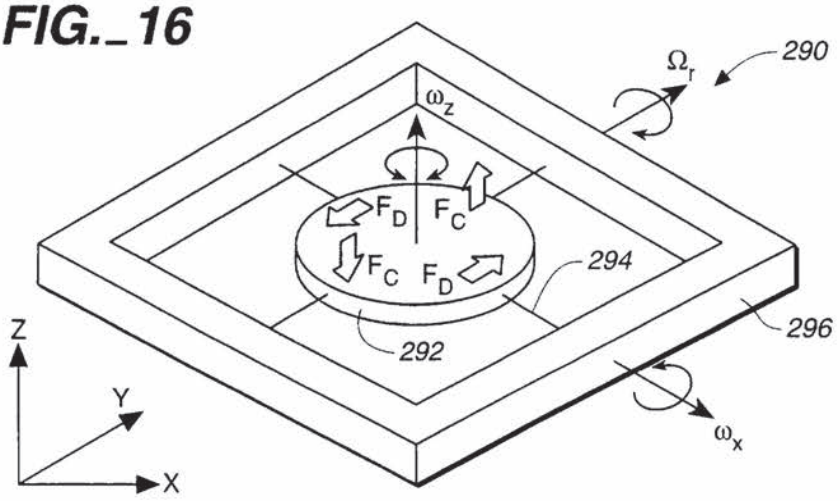
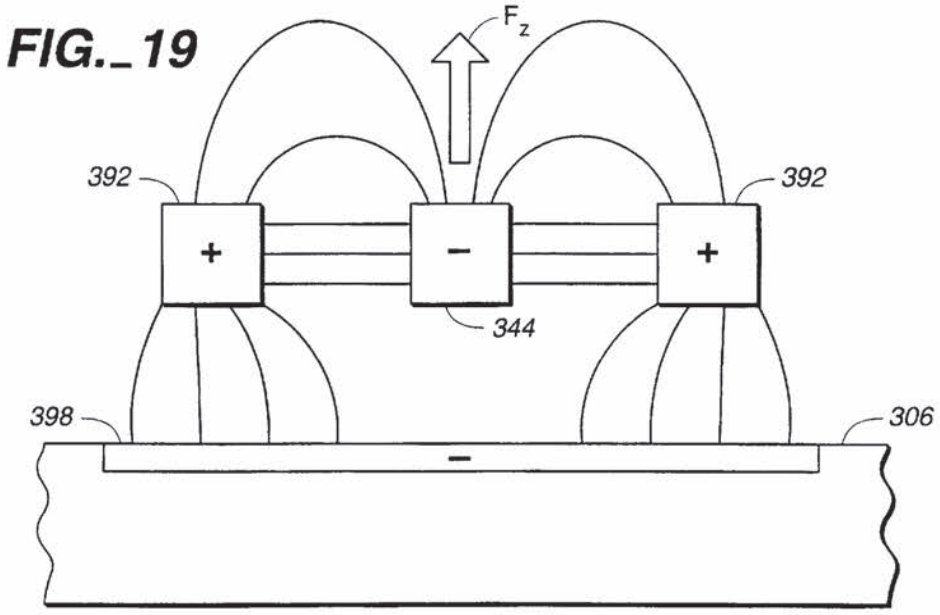
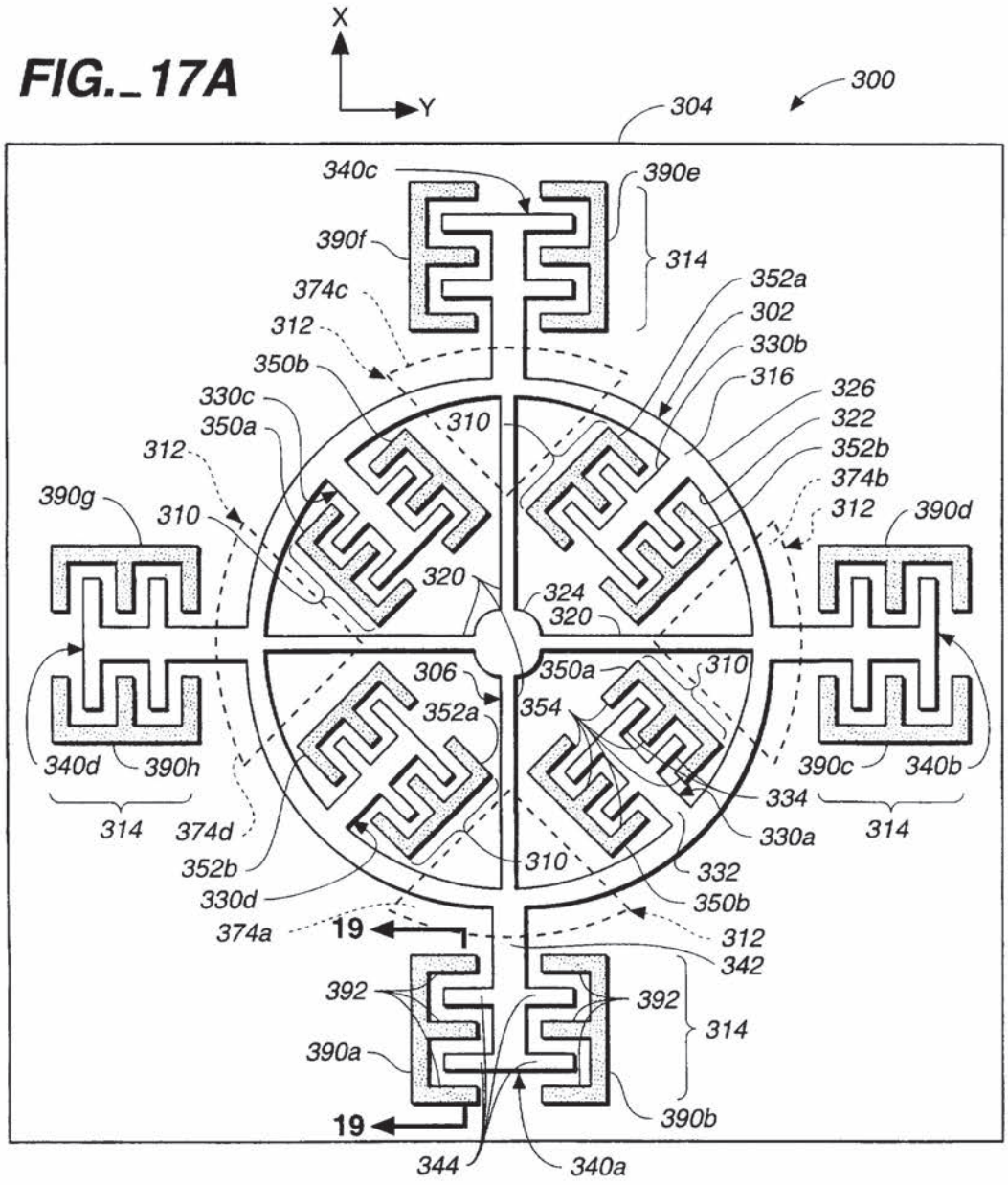


FIG._19



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FIG._17A



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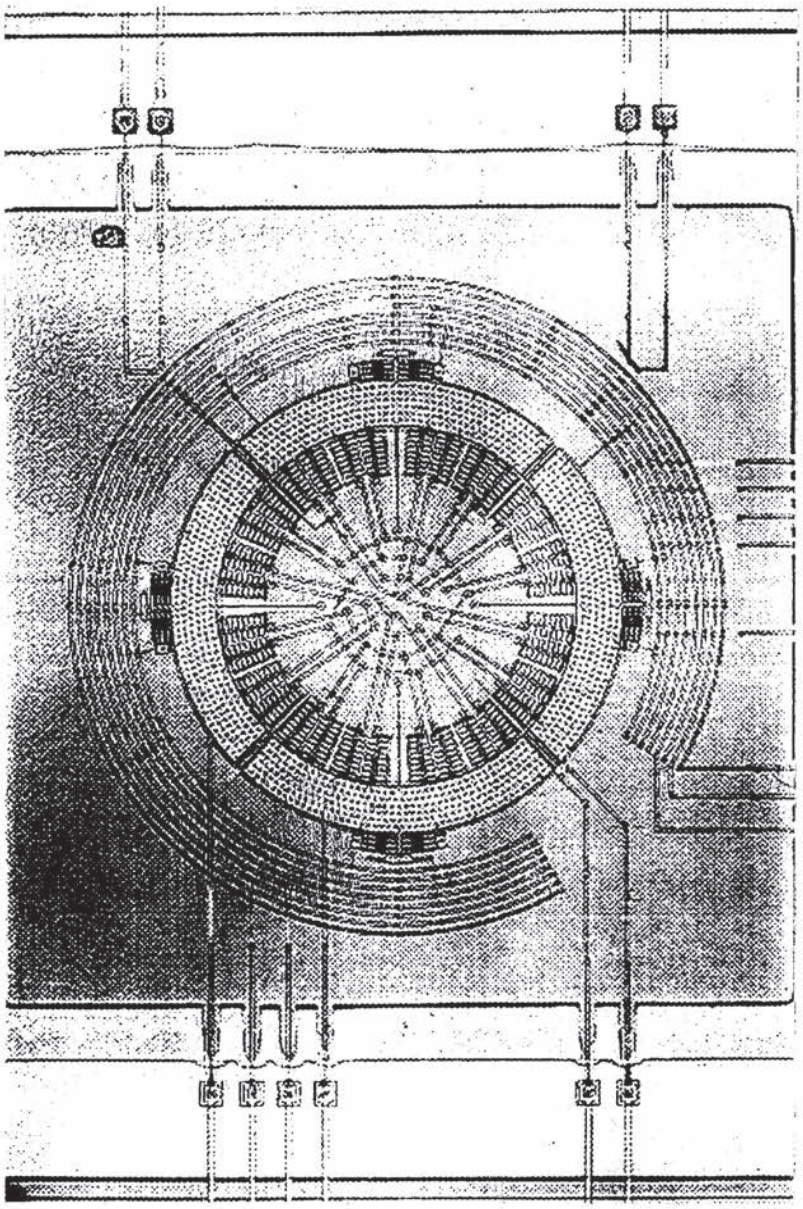
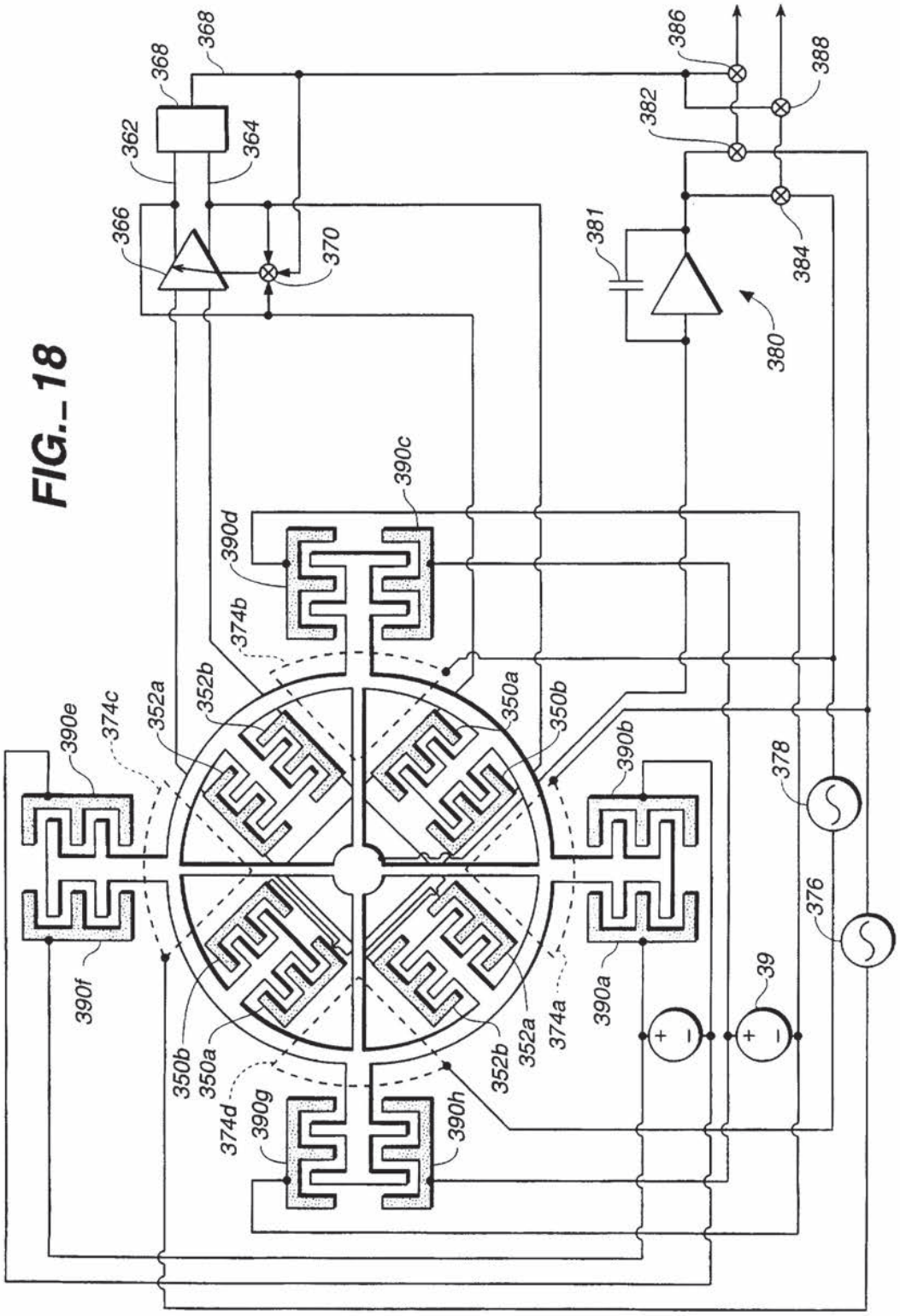


FIG._17B

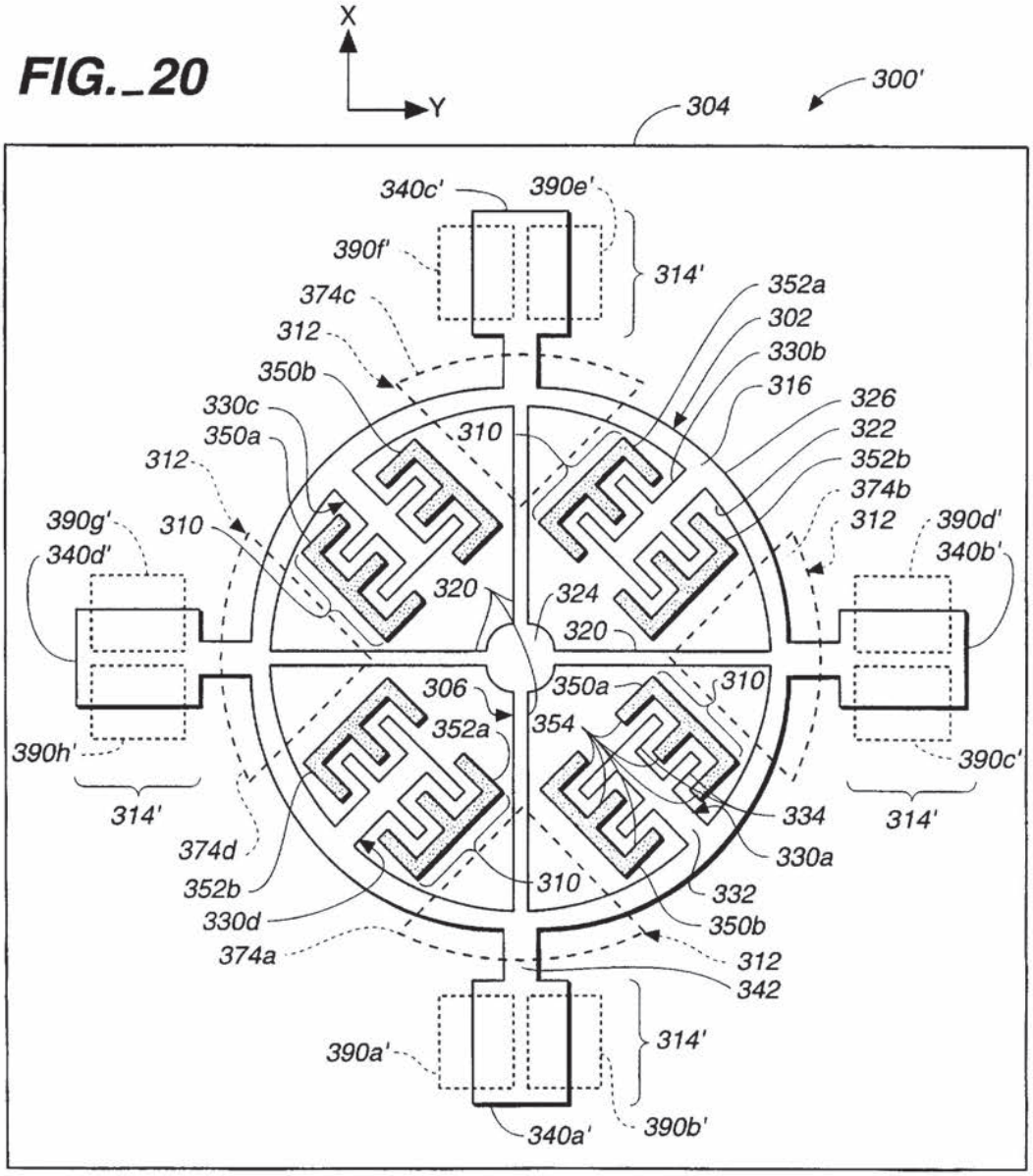
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FIG._18



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FIG._20



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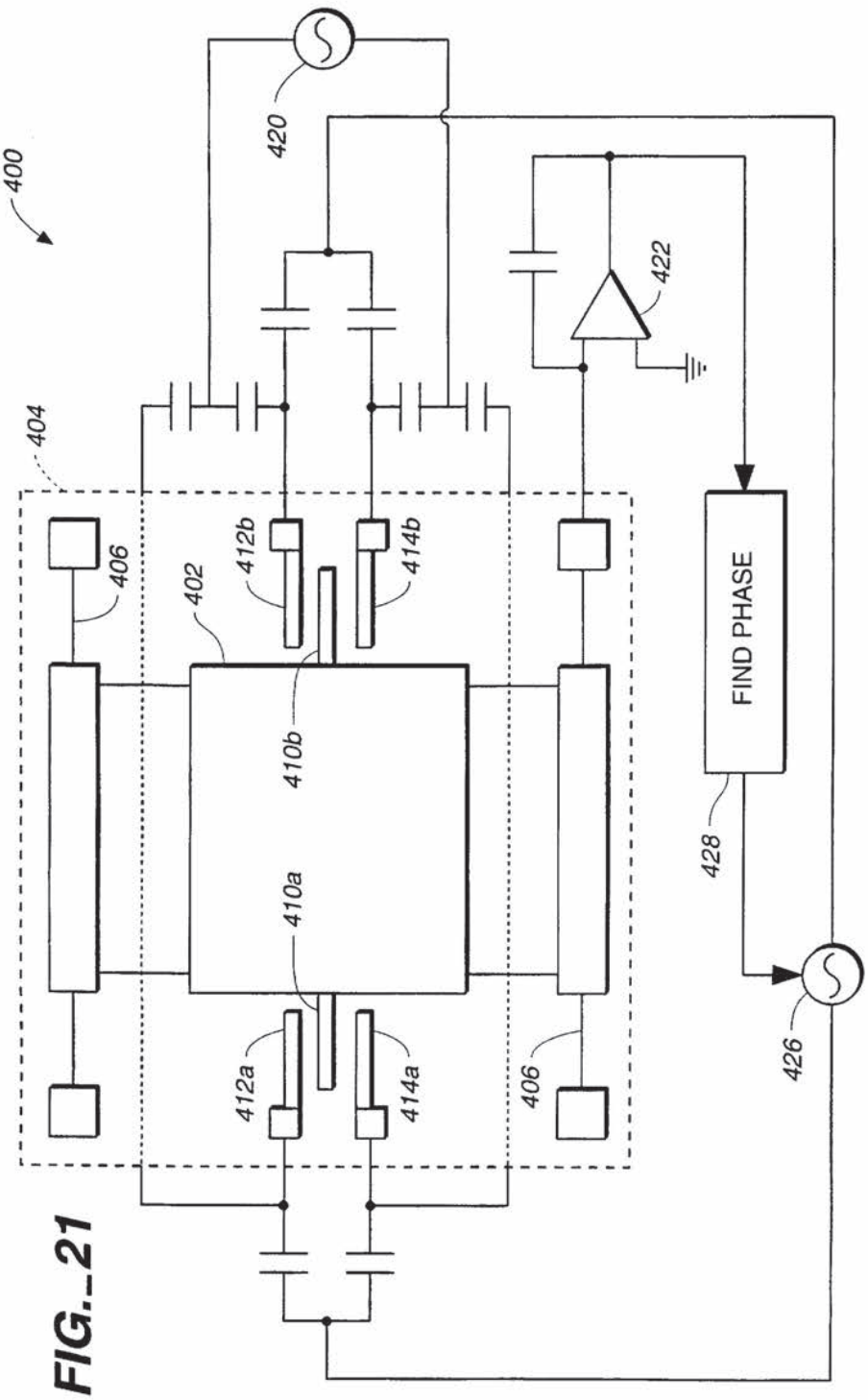


FIG._21

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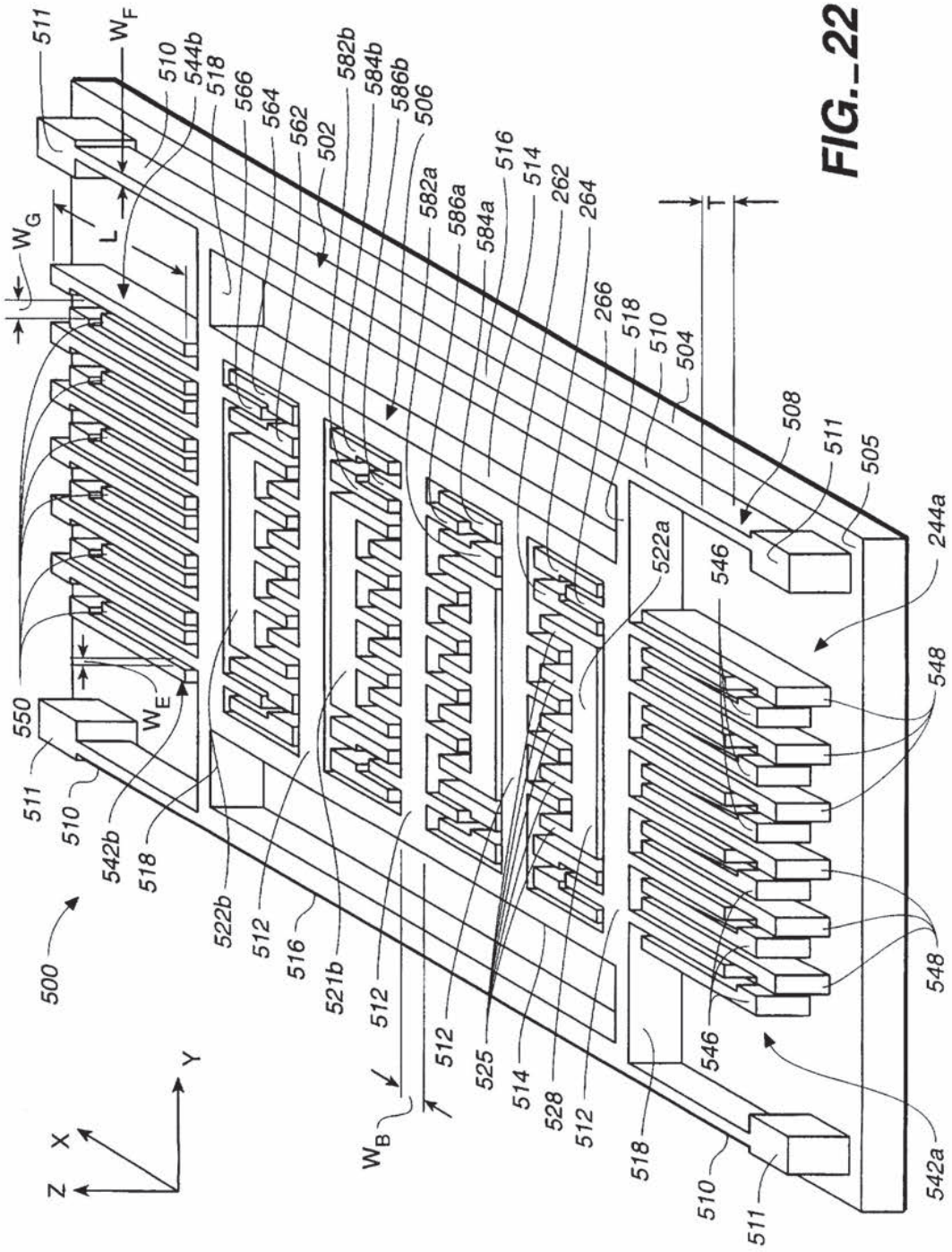


FIG._22

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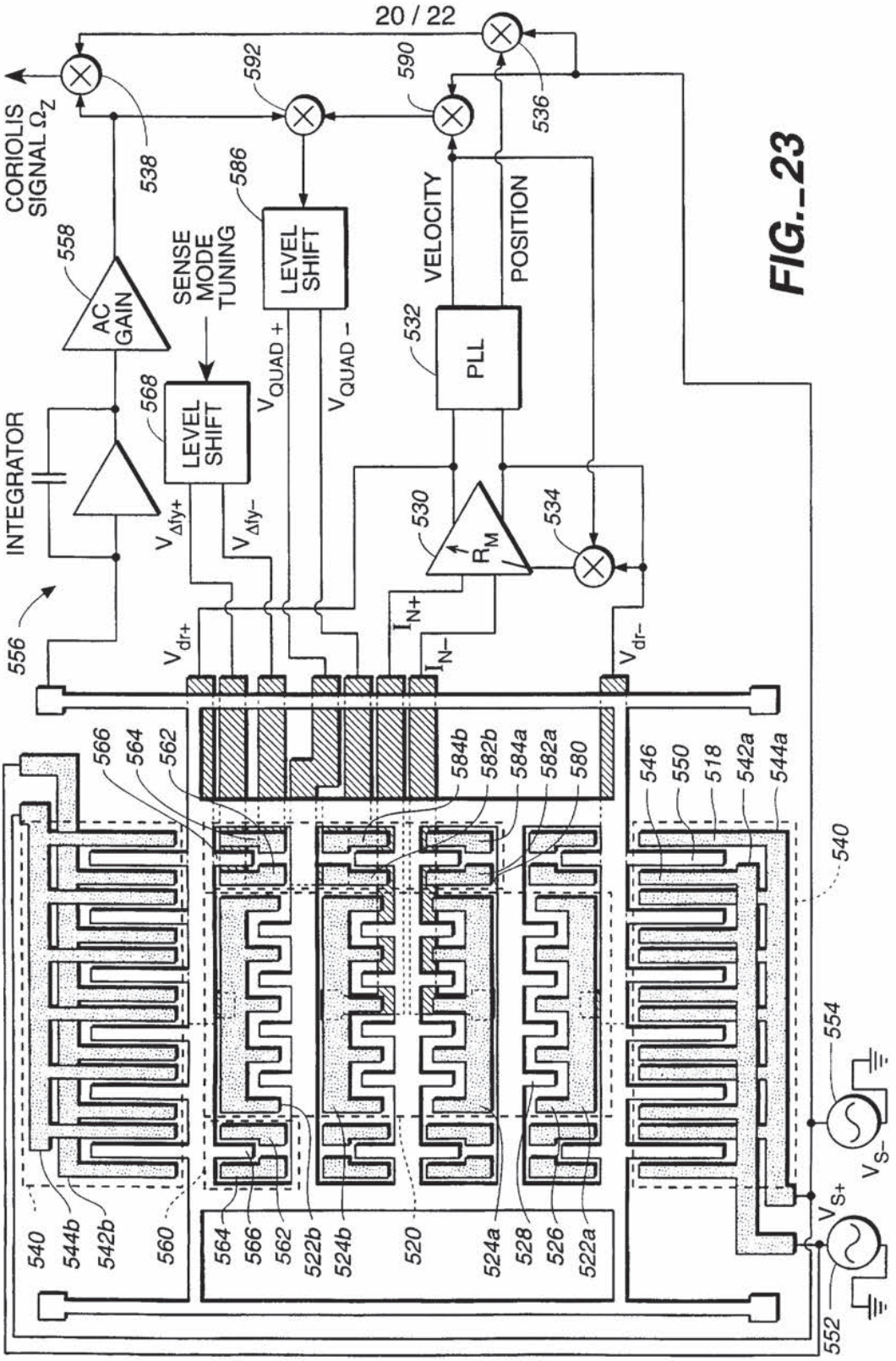


FIG._23

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FIG._24A

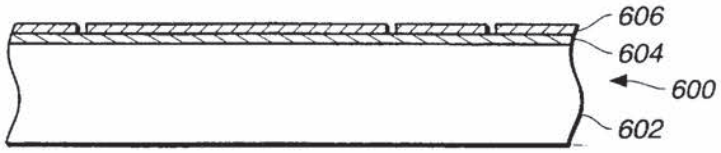


FIG._24B

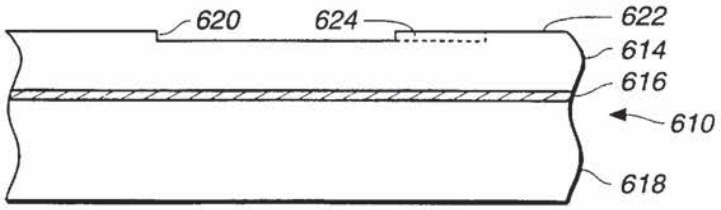


FIG._24C

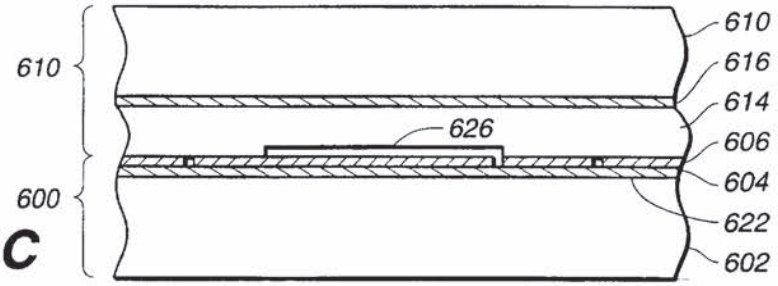


FIG._24D

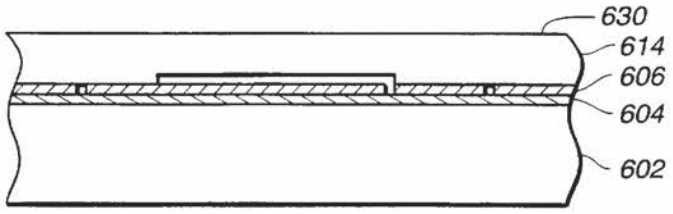
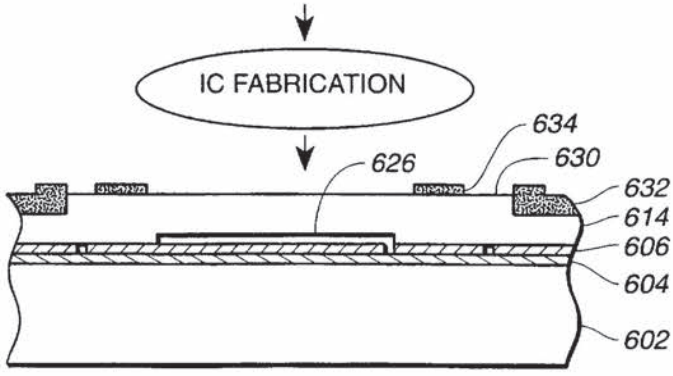


FIG._24E



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FIG._24F

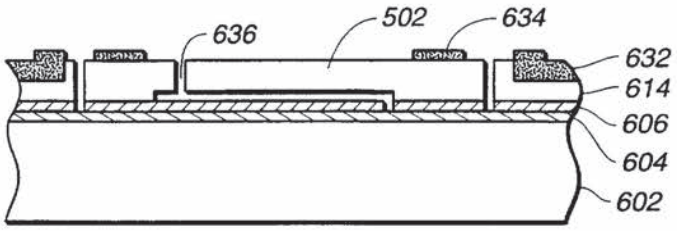
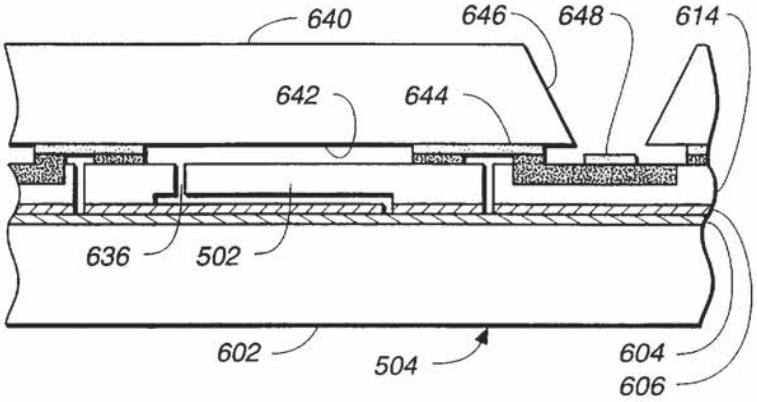


FIG._24G



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EXHIBIT 1057C

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1. WO1997045699 - MICROMACHINED VIBRATORY RATE GYROSCOPE

PCT Biblio. Data | Description | Claims | Drawings | National Phase | Patent Family | Notices | Documents

PermaLink Machine translation

Publication Number
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Publication Date
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PCT/US1997/009150

International Filing Date
30.05.1997

Chapter 2 Demand Filed
16.12.1997

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G01C 19/5719 2012.1

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G01C 19/5719

Applicants
THE REGENTS OF THE UNIVERSITY OF CALIFORNIA [US]/
21st floor
300 Lakeside Drive
Oakland, CA 94612
[US]United States of America

Inventors
CLARK, William, A.
JUNEAU, Thor
HOWE, Roger, T.

Agents
EGAN, William, J., III
Fish & Richardson P.C.
Suite 100
2200 Sand Hill Road
Menlo Park, CA 94025
United States of America

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08/658,924 31.05.1996 US

Publication Language
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Filing Language
English (en)

Designated States
View all

Title
(EN) MICROMACHINED VIBRATORY RATE GYROSCOPE
(FR) GYROSCOPE MICRO-USINE A STRUCTURE VIBRATOIRE

Abstract
(EN) A microfabricated gyroscope (20) includes proof mass (22) connected to a frame or substrate (24) to measure rotation about an axis parallel to the surface of the substrate. The micromachined gyroscope includes a suspension system (30), a drive system (32) used to sustain oscillation of the proof mass (22) and a sensing system (34) used to detect deflections of the proof mass (22). The proof mass includes a plurality of electrode fingers (38). Voltage sources (120, 122, 124, 126) apply a voltage to sense fingers (74a-b, 76a-b) of sense electrodes (62a-b) to provide bias voltages to nullify quadrature error, select or adjust the resonant frequency of vibrations of the mass along the sense axis and cancel any centrifugal or other low-frequency forces.
(FR) L'invention concerne un gyroscope micro-usiné qui permet de mesurer la rotation autour d'un axe parallèle à la surface d'un substrat. On peut appliquer une différence de tension entre des paires d'électrodes digitées afin de réduire l'erreur en quadrature. Le gyroscope considéré est doté d'un structure vibratoire et d'électrodes interdigitées ayant un rapport d'allongement élevé.

Related patent documents
US5992233 US6067858 DE000069735759 EP0902876 AU1997034744 JP2002515976 US6296779 US6250156

Latest bibliographic data on file with the International Bureau

The publication of an international application under the Patent Cooperation Treaty in PATENTSCOPE (which constitutes an element of the Gazette) does not imply the expression of any opinion whatsoever on the part of the International Bureau of WIPO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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1. WO1997045699 - MICROMACHINED VIBRATORY RATE GYROSCOPE

PCT Biblio. Data Description Claims Drawings National Phase Patent Family Notices Documents

PermaLink

Published International Application			
Date	Title	View	Download
10.01.2002	Later publication of international search report (A3 02/2002)	PDF 3 p.	PDF 3 p. ZIP XML + TIFFs
04.12.1997	Initial Publication without ISR (A2 52/1997)	PDF 102 p.	PDF 102 p. ZIP XML + TIFFs

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EXHIBIT 1057D

SECTION II

NOTICES AND INFORMATION RELATING TO PUBLISHED INTERNATIONAL APPLICATIONS AND/OR ENTRIES IN SECTION I

NOTIFICATIONS ET INFORMATIONS RELATIVES AUX DEMANDES INTERNATIONALES PUBLIÉES ET/OU AUX RUBRIQUES DE LA SECTION I

ANNOUNCEMENT OF THE LATER PUBLICATION OF AMENDED CLAIMS AND, WHERE APPLICABLE, STATEMENT UNDER ARTICLE 19

ANNONCE DE LA PUBLICATION ULTÉRIEURE DES REVENDICATIONS MODIFIÉES ET, S'IL Y A LIEU, DE LA DÉCLARATION SELON L'ARTICLE 19

Amended claims and a statement under Article 19, relating to the already published international applications listed below, have been published on the same date as the present issue of the PCT Gazette, together with updated versions of the front pages of the pamphlets in which the said applications were published. The page numbering of the amended claims is in accordance with the page numbering of the said pamphlets.

Les revendications modifiées en vertu de l'article 19, ainsi que la déclaration, relatives aux demandes internationales mentionnées ci-dessous, ont été publiées à la date de parution du présent numéro de la Gazette du PCT avec des versions mises à jour des pages de couverture des brochures dans lesquelles lesdites demandes internationales ont été publiées. La pagination des revendications modifiées correspond à la pagination desdites brochures.

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**	**Amended Claims Received on** **Revendications modifiées reçues le**
PCT/CA97/00560	WO 98/05685	C07K 14/78	14 May/mai 1998
PCT/DE97/02474	WO 98/18705	B65H 45/16	15 May/mai 1998
PCT/DK97/00338	WO 98/10409	G10C 3/16	31 Mar/mar 1998
PCT/US97/18487	WO 98/15176	A01M 1/20	27 Mar/mar 1998
PCT/US97/19682	WO 98/18839	C08F 290/04	13 May/mai 1998
PCT/US97/20198	WO 98/21661	G06F 13/00	18 May/mai 1998

ANNOUNCEMENT OF THE WITHDRAWAL OF INTERNATIONAL APPLICATIONS AFTER INTERNATIONAL PUBLICATION

ANNONCE DU RETRAIT DE DEMANDES INTERNATIONALES APRÈS PUBLICATION INTERNATIONALE

The international applications listed below have been (considered) withdrawn after international publication.

Les demandes internationales indiquées ci-dessous ont été (considérées) retirées après publication internationale.

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**
PCT/DE97/02553	WO 98/18752	C07C 209/68
PCT/EP97/00513	WO 97/33160	G01N 23/04
PCT/IB 97/01459	WO 98/22044	A61F 2/06
PCT/IT 97/00259	WO 98/19094	F16L 17/06
PCT/RU96/00318	WO 98/20757	A24C 5/40
PCT/US97/02981	WO 97/30493	H01R 29/00
PCT/US97/20071	WO 98/20889	A61K 38/18

ANNOUNCEMENT OF THE WITHDRAWAL OF DESIGNATIONS AFTER INTERNATIONAL PUBLICATION

ANNONCE DU RETRAIT DE DÉSIGNATIONS APRÈS PUBLICATION INTERNATIONALE

The designations of the States indicated in relation to the international applications listed below have been (considered) withdrawn after international publication.

Les désignations des États indiquées dans les demandes internationales mentionnées ci-dessous ont été (considérées) retirées après publication internationale.

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**	**States** **États**
PCT/KG96/00001	WO 98/05885	F16H 21/16	AU, BG, BR, CA, CN, CZ, FI, HU, KP, MN, MX, PL, RO, ARIPO patent (KE, LS, MW, SD, SZ, UG), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG) AU, BG, BR, CA, CN, CZ, FI, HU, KP, MN, MX, PL, RO, brevet ARIPO (KE, LS, MW, SD, SZ, UG), brevet OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG)
PCT/EP97/05298	WO 98/14675	E04D 3/36	DE
PCT/EP97/05570	WO 98/19071	F16B 35/04	DE

ANNOUNCEMENT OF THE LATER PUBLICATION OF REVISED VERSIONS OF INTERNATIONAL SEARCH REPORTS

ANNONCE DE LA PUBLICATION ULTÉRIEURE DE VERSIONS RÉVISÉES DE RAPPORTS DE RECHERCHE INTERNATIONALE

Revised versions of international search reports established in relation to the international applications listed below have been issued by the competent International Searching Authorities. The said revised versions have been published on the same date as the present issue of the PCT Gazette, together with updated versions of the front pages of the corresponding pamphlets bearing (in the language of publication) the indication "Published with a revised version of the international search report."

L'administration chargée de la recherche internationale compétente a établi des versions révisées des rapports de recherche internationale relatifs aux demandes internationales mentionnées ci-dessous. Lesdites versions révisées sont publiées à la date de parution du présent numéro de la Gazette du PCT, avec des versions mises à jour des pages de couverture des brochures correspondantes portant (dans la langue de publication) la mention "Publiée avec une version révisée du rapport de recherche internationale".

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**International Publication Numbers** **Numéros de publication internationale**
PCT/FI 96/00618	WO 97/18681	H04Q 7/24
PCT/DE97/01624	WO 98/06136	H01L 29/78
PCT/JP 97/03065	WO 98/14785	G01N 35/10
PCT/JP 97/03474	WO 98/14507	C08J 9/06
PCT/NO97/00002	WO 97/25137	B01J 20/04

ANNOUNCEMENT OF THE LATER PUBLICATION OF INTERNATIONAL SEARCH REPORTS

ANNONCE DE LA PUBLICATION ULTÉRIEURE DE RAPPORTS DE RECHERCHE INTERNATIONALE

The international search reports, relating to the international applications listed below, which were not available when the international applications were published pursuant to Article 21(2)(a), have been published on the same date as the present issue of the PCT Gazette together with revised versions of the front pages of the pamphlets comprising the earlier publication and bearing the same international publication number.

Les rapports de recherche internationale relatifs aux demandes internationales mentionnées ci-dessous, rapports qui n'étaient pas disponibles lorsque ces demandes internationales ont été publiées en vertu de l'article 21.2)a), sont publiés à la même date que le présent numéro de la Gazette du PCT avec des versions révisées des pages de couverture des brochures publiées antérieurement. Ces versions révisées des pages de couverture portent le même numéro de publication internationale que les brochures publiées antérieurement.

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**
PCT/CA97/00728	WO 98/14445	C07D 471/04
PCT/DE97/02529	WO 98/19453	H04N 3/15
PCT/DE97/02626	WO 98/21873	H04M 15/00
PCT/EP97/06004	WO 98/21758	H01L 33/00
PCT/EP97/06095	WO 98/20123	C12N 15/12
PCT/EP97/06276	WO 98/21362	C12Q 1/68
PCT/FI 97/00544	WO 98/11675	H04B 1/707
PCT/FI 97/00650	WO 98/20663	H04M 1/274
PCT/GB97/02906	WO 98/18299	E05D 15/46
PCT/IB 97/01085	WO 98/11687	H04J 3/22
PCT/IB 97/01193	WO 98/20603	H02M 3/137
PCT/IB 97/01247	WO 98/16370	B30B 15/16
PCT/IL 97/00228	WO 98/01374	A01K 1/035
PCT/IL 97/00282	WO 98/08974	C12Q 1/68
PCT/IL 97/00352	WO 98/19130	A41H 1/02
PCT/NZ97/00114	WO 98/11765	H01F 27/08
PCT/SE97/01720	WO 98/17018	H04B 7/26
PCT/SE97/01790	WO 98/20577	H01Q 1/24
PCT/US97/06884	WO 97/40464	G06K 19/16
PCT/US97/08183	WO 97/44158	B24B 49/00
PCT/US97/09996	WO 97/48234	G06F 13/00
PCT/US97/10116	WO 98/00510	C11D 17/00
PCT/US97/11454	WO 98/11005	B65G 17/46
PCT/US97/12347	WO 98/02582	C12Q 1/68
PCT/US97/13135	WO 98/07183	H01L 41/08
PCT/US97/13372	WO 98/03956	G09F 19/12
PCT/US97/13785	WO 98/10386	G11B 7/24
PCT/US97/14215	WO 98/10178	F02M 37/04
PCT/US97/14274	WO 98/06889	F26B 3/00
PCT/US97/14430	WO 98/07459	A61M 11/00
PCT/US97/14662	WO 98/09699	F01N 3/20
PCT/US97/15045	WO 98/08370	F01D 5/14
PCT/US97/15293	WO 98/10693	A61B 17/04
PCT/US97/15390	WO 98/09529	A22C 25/16
PCT/US97/15417	WO 98/10597	G06F 3/00

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ANNOUNCEMENT OF THE LATER PUBLICATION OF INTERNATIONAL SEARCH REPORTS (Continued)

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International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**
PCT/US97/15643	WO 98/10252	G01H 11/06
PCT/US97/16575	WO 98/12449	F16F 7/01
PCT/US97/16685	WO 98/15109	H04M 17/02
PCT/US97/16864	WO 98/13265	B29D 22/00
PCT/US97/16911	WO 98/13740	G06F 12/00
PCT/US97/17315	WO 98/16946	H01J 37/09
PCT/US97/17539	WO 98/14220	A61K 51/08
PCT/US97/17614	WO 98/14594	C12N 15/55
PCT/US97/17721	WO 98/16350	B25B 13/46
PCT/US97/17775	WO 98/15519	C07C 51/47
PCT/US97/17948	WO 98/15638	C12N 15/86
PCT/US97/17971	WO 98/14224	A61F 11/00
PCT/US97/17974	WO 98/15112	A63B 21/00
PCT/US97/18037	WO 98/15355	G01N 1/10
PCT/US97/18223	WO 98/15887	G06F 17/00
PCT/US97/18268	WO 98/18117	G06K 9/00
PCT/US97/18534	WO 98/16056	H04N 5/91
PCT/US97/18554	WO 98/17044	H04M 1/24
PCT/US97/18676	WO 98/19214	G03B 27/42
PCT/US97/18809	WO 98/16170	B68G 5/00
PCT/US97/18865	WO 98/17194	A61C 5/02
PCT/US97/18956	WO 98/17315	A61K 9/70
PCT/US97/19080	WO 98/20615	G01F 1/60
PCT/US97/19091	WO 98/17552	A47B 96/06
PCT/US97/19702	WO 98/20666	H04M 1/66
PCT/US97/20094	WO 98/19673	A61K 31/165
PCT/US97/20494	WO 98/19625	A61B 17/00
PCT/US97/20523	WO 98/20314	G01N 25/20
PCT/US97/20699	WO 98/20686	G05B 19/42
PCT/US97/20936	WO 98/21637	G06E 1/00
PCT/US97/21790	WO 98/21697	G06K 9/74

CORRECTIONS OF ENTRIES IN SECTION I

CORRECTIONS DE RUBRIQUES DE LA SECTION I

The entries appearing in Section I of the PCT Gazette, identified by the international publication numbers listed below, are corrected as follows:

Les rubriques reproduites à la Section I de la Gazette du PCT, identifiées par les numéros de publication internationale mentionnés ci-dessous, sont corrigées comme suit :

International Publication Numbers **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**		**Gazette Issue Numbers** **Numéros de Gazette**	**Corrections**
WO 97/06802(1)	A61K	31/495	10/1997	under (72, 75) replace "STOKES, Elaine, Sophie, Elisabeth" by "STOKES, Elaine, Sophie, Elizabeth" sous les numéros (72, 75) remplacer "STOKES, Elaine, Sophie, Elisabeth" par "STOKES, Elaine, Sophie, Elizabeth"
WO 97/31875(1)	C04B	28/02	38/1997	under (72) replace "GREINE, Klaus" by "GREIWE, Klaus" sous le numéro (72) remplacer "GREINE, Klaus" par "GREIWE, Klaus"
WO 97/47428(1)	B23Q	1/54	54/1997	under (22) replace "10 June 1997 (10.06.97)" by "11 June 1997 (11.06.97)" sous le numéro (22) remplacer "10 juin 1997 (10.06.97)" par "11 juin 1997 (11.06.97)"
WO 98/02580(1)	C12Q	1/68	03/1998	under (72) replace the existing text by "LANE, Michael, J.; 3044 Claybourne Lane, Baldwinsville, NY 13027 (US). BENIGHT, Albert, S.; 1630 Valley View Drive, Schaumburg, IL 60193 (US). FALDASZ, Brian, D.; 4 Bellevue Terrace, Maynard, MA 01754 (US)." sous le numéro (72) remplacer le texte existant par "LANE, Michael, J.; 3044 Claybourne Lane, Baldwinsville, NY 13027 (US). BENIGHT, Albert, S.; 1630 Valley View Drive, Schaumburg, IL 60193 (US). FALDASZ, Brian, D.; 4 Bellevue Terrace, Maynard, MA 01754 (US)."
WO 98/04560(1)	C07D	487/04	05/1998	under (72, 75) replace "STERNFIELD, Francine" by "STERNFELD, Francine" sous les numéros (72, 75) remplacer "STERNFIELD, Francine" par "STERNFELD, Francine"
WO 98/04690(1)	C12N	15/12	05/1998	under (72, 75) replace "BIDWELL, Christopher, A. [-/US]" by "BIDWELL, Christopher, A. [US/US]" and "SPURLOCK, Michael, E. [-/US]" by "SPURLOCK, Michael, E. [US/US]" sous les numéros (72, 75) remplacer "BIDWELL, Christopher, A. [-/US]" par "BIDWELL, Christopher, A. [US/US]" et "SPURLOCK, Michael, E. [-/US]" par "SPURLOCK, Michael, E. [US/US]"
WO 98/06973(1)	F17D	3/00	07/1998	under (81) add "AU, CA, CN, JP, MX"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "AU, CA, CN, JP, MX"; en raison de la transmission tardive par l'office récepteur
WO 98/07946(1)	E06B	3/01	08/1998	under (72, 75) replace "LOSCH, Max [-/-]" by "LOSCH, Max [DE/DE]" sous les numéros (72, 75) remplacer "LOSCH, Max [-/-]" par "LOSCH, Max [DE/DE]"
WO 98/08569(1)	A62B	1/12	09/1998	under (81) add "GH, SL, YU, ZW" sous le numéro (81) ajouter "GH, SL, YU, ZW"
WO 98/09973(1)	C07F	5/02	10/1998	under (30) replace "Not furnished" by "08/923,054" sous le numéro (30) remplacer "Non communiqué" par "08/923,054"

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CORRECTIONS OF ENTRIES IN SECTION I (Continued)

CORRECTIONS DE RUBRIQUES DE LA SECTION I (Suite)

International Publication Numbers **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**	**Gazette Issue Numbers** **Numéros de Gazette**	**Corrections**
WO 98/10334(1)	G03F 7/00	10/1998	under (81) delete "Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM)" sous le numéro (81) supprimer "brevet eurasien (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM)"
WO 98/11859(1)	A61G 7/10	12/1998	under (72, 75) replace “WHATLEY, David, Richard" by "WHATLEY, David, Reginald" sous les numéros (72, 75) remplacer "WHATLEY, David, Richard" par "WHATLEY, David, Reginald"
WO 98/12208(1)	C07K 1/16	12/1998	under (30) replace "Not furnished" by "08/934,139" sous le numéro (30) remplacer "Non communiqué" par "08/934,139"
WO 98/13358(1)	C07D 295/22	13/1998	under (30) replace "5 May 1997 (05.05.97)" by "7 May 1997 (07.05.97)" and under (72, 75) replace "SRINIVASAN, Aloka [-/US]" by "SRINIVASAN, Aloka [IN/US]" sous le numéro (30) remplacer "5 mai 1997 (05.05.97)" par "7 mai 1997 (07.05.97)" et sous les numéros (72, 75) remplacer "SRINIVASAN, Aloka [-/US]" par "SRINIVASAN, Aloka [IN/US]"
WO 98/14447(1)	C07D 471/04	14/1998	under (81) add "IL, TR"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "IL, TR"; en raison de la transmission tardive par l’office récepteur
WO 98/14606(1)	C12Q 1/42	14/1998	under (30) replace "1 October 1996 (01.10.96)" by "4 October 1996 (04.10.96)" sous le numéro (30) remplacer "1 octobre 1996 (01.10.96)" par "4 octobre 1996 (04.10.96)"
WO 98/14641(1)	C25D 5/02	14/1998	under (30) replace "1 October 1996 (01.10.96)" by "2 October 1996 (02.10.96)" sous le numéro (30) remplacer "1 octobre 1996 (01.10.96)" par "2 octobre 1996 (02.10.96)"
WO 98/15222(1)	A61B 3/10	15/1998	under (30) replace "Not furnished" by "08/947,697" sous le numéro (30) remplacer "Non communiqué" par "08/947,697"
WO 98/15456(1)	B64F 1/34	15/1998	under (30) replace "Not furnished" by "08/938,623" sous le numéro (30) remplacer "Non communiqué" par "08/938,623"
WO 98/15656(1)	C12Q 1/68	15/1998	under (71) replace "UNIVERSITY OF NEW MEXICO [-/US]" by "UNIVERSITY OF NEW MEXICO [US/US]" sous le numéro (71) remplacer "UNIVERSITY OF NEW MEXICO [-/US]" par "UNIVERSITY OF NEW MEXICO [US/US]"

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CORRECTIONS OF ENTRIES IN SECTION I (Continued)

CORRECTIONS DE RUBRIQUES DE LA SECTION I (Suite)

International Publication Numbers **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**	**Gazette Issue Numbers** **Numéros de Gazette**	**Corrections**
WO 98/15688(1)	D21F 3/00	15/1998	under (81) add "CN, ID, KP, VN"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "CN, ID, KP, VN"; en raison de la transmission tardive par l'office récepteur
WO 98/16225(1)	A61K 31/415	16/1998	under (81) add "IL"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "IL"; en raison de la transmission tardive par l'office récepteur
WO 98/16967(1)	H04Q 1/42	16/1998	under (30) replace "15 October 1996 (15.10.96)" by "13 September 1996 (13.09.96)" sous le numéro (30) remplacer "15 octobre 1996 (15.10.96)" par "13 septembre 1996 (13.09.96)"
WO 98/17651(1)	C07D 235/06	17/1998	under (81) add "IL, TR"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "IL, TR"; en raison de la transmission tardive par l'office récepteur
WO 98/17859(1)	D21F 1/00	17/1998	under (81) add "YU"; due to late transmittal by the receiving Office sous le numéro (81) ajouter "YU"; en raison de la transmission tardive par l'office récepteur
WO 98/18547(1)	B01J 8/02	18/1998	under (54) the title in English should read "PROCESS AND REACTOR FOR EPOXIDATION WITH ENERGY RECOVERY" sous le numéro (54) le titre en anglais doit se lire "PROCESS AND REACTOR FOR EPOXIDATION WITH ENERGY RECOVERY"
WO 98/18680(1)	B65D 5/40	18/1998	under (54) the title in English should read "A PROTECTED PACKAGING" sous le numéro (54) le titre en anglais doit se lire "A PROTECTED PACKAGING"
WO 98/18814(1)	C07K 1/00	18/1998	under (30) replace "Not furnished" by "60/063,140" sous le numéro (30) remplacer "Non communiqué" par "60/063,140"
WO 98/18846(1)	C08G 63/16	18/1998	under (30) replace "Not furnished" by "08/951,917" sous le numéro (30) remplacer "Non communiqué" par "08/951,917"
WO 98/18865(1)	C08L 101/00	18/1998	under (72, 75) replace "SEHANOBISH, Kalyan [US/US]" by "SEHANOBISH, Kalyan [IN/US]" sous les numéros (72, 75) remplacer "SEHANOBISH, Kalyan [US/US]" par "SEHANOBISH, Kalyan [IN/US]"

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CORRECTIONS OF ENTRIES IN SECTION I (Continued)

CORRECTIONS DE RUBRIQUES DE LA SECTION I (Suite)

International Publication Numbers **Numéros de publication internationale**	**First International Patent Classification Symbols** **Premiers symboles de la classification internationale des brevets**	**Gazette Issue Numbers** **Numéros de Gazette**	**Corrections**
WO 98/19718(1)	A61L 15/18	19/1998	under (51) replace "A61L 15/18" by "A61L 15/28" sous le numéro (51) remplacer "A61L 15/18" par "A61L 15/28"
WO 98/20721(1)	Not classified Non classée	20/1998	under (51) replace "Not classified" by "H01L 41/083" sous le numéro (51) remplacer "Non classée" par "H01L 41/083"
WO 98/21072(1)	B60R 21/16	20/1998	the code identifying the kind of document to which the pamphlet relates should read "A1" instead of "A2" le code identifiant le type de document que constitue la brochure doit se lire "A1" au lieu de "A2"
WO 98/21568(1)	G01N 21/89	20/1998	under (54) replace the existing text by "ARRANGEMENT AND METHOD FOR MARKING DEFECTS" sous le numéro (54) remplacer le texte existant par "AGENCEMENT ET PROCEDE POUR MARQUER DES DEFAUTS"
WO 98/21916(1)	H05B 1/02	20/1998	under (54) replace the existing text by "A DEVICE IN A MONITORING UNIT FOR HEAT-EMITTING OBJECTS" sous le numéro (54) remplacer le texte existant par "DISPOSITIF POUR UNITE DE SURVEILLANCE POUR OBJETS DIFFUSANT DE LA CHALEUR"
WO 98/22132(1)	A61K 38/46	21/1998	under "Published", replace the existing text by "Without international search report and to be republished upon receipt of that report." and replace "A1" by "A2" sous la mention "Publiée", remplacer le texte existant par "Sans rapport de recherche internationale, sera republiée dès réception de ce rapport." et remplacer "A1" par "A2"
WO 98/22901(1)	G06F 27/00	21/1998	under (51) replace "G06F 27/00" by "G09F 27/00" sous le numéro (51) remplacer "G06F 27/00" par "G09F 27/00"
WO 98/23013(1)	H02B 53/30	21/1998	under (51) replace "H02B 53/30" by "H02B 1/30" sous le numéro (51) remplacer "H02B 53/30" par "H02B 1/30"

(1) A corrected version of the front page of the corresponding pamphlet has been published on the same date as the present issue of the PCT Gazette.

(1) Une version corrigée de la page de couverture de la brochure correspondante a été publiée à la date de parution du présent numéro de la Gazette du PCT.

CORRECTED VERSIONS OF PAMPHLETS

VERSIONS CORRIGÉES DE BROCHURES

Corrected versions of the pamphlets, identified below by their international publication number, have been published on the same date as the present issue of the PCT Gazette.

Des versions corrigées des brochures, identifiées ci-dessous par leur numéro de publication internationale, ont été publiées à la date de parution du présent numéro de la Gazette du PCT.

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 97/06402	PCT/US96/12749	pages 66-71, claims, added pages 66-71, revendications, ajoutées
WO 97/34808	PCT/US97/04288	pages 1/2-2/2, drawings, replaced by new pages 1/2-2/2; due to late transmittal by the receiving Office pages 1/2-2/2, dessins, remplacées par de nouvelles pages 1/2-2/2; en raison de la transmission tardive par l'office récepteur
WO 97/39293	PCT/US97/05488	pages 1/9-9/9, drawings, replaced by new pages 1/9-9/9; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 97/41263	PCT/US97/07676	pages 4 and 16, description, replaced by new pages 4 and 16; pages 1/11-11/11, drawings, replaced by new pages 1/11-11/11; due to late transmittal by the receiving Office pages 4 et 16, description, remplacées par de nouvelles pages 4 et 16; pages 1/11-11/11, dessins, remplacées par de nouvelles pages 1/11-11/11; en raison de la transmission tardive par l'office récepteur
WO 97/41558	PCT/US97/07291	pages 1/4-4/4, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/4-4/4, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 97/42879	PCT/US97/07977	pages 1/31-31/31, drawings, replaced by new pages 1/26-26/26; due to late transmittal by the receiving Office pages 1/31-31/31, dessins, remplacées par de nouvelles pages 1/26-26/26; en raison de la transmission tardive par l'office récepteur
WO 97/45384	PCT/US97/09573	page 1/1, drawings, replaced by a new page 1/1; due to late transmittal by the receiving Office page 1/1, dessins, remplacée par une nouvelle page 1/1; en raison de la transmission tardive par l'office récepteur
WO 97/47083	PCT/US97/09382	pages 1/13-13/13, drawings, replaced by new pages 1/13-13/13; due to late transmittal by the receiving Office pages 1/13-13/13, dessins, remplacées par de nouvelles pages 1/13-13/13; en raison de la transmission tardive par l'office récepteur
WO 97/47329	PCT/US97/09292	pages 75-84, claims, replaced by new pages 75-84; due to late transmittal by the receiving Office pages 75-84, revendications, remplacées par de nouvelles pages 75-84; en raison de la transmission tardive par l'office récepteur
WO 97/47358	PCT/US97/09884	pages 21-25, claims, replaced by new pages 21-25; due to late transmittal by the receiving Office pages 21-25, revendications, remplacées par de nouvelles pages 21-25; en raison de la transmission tardive par l'office récepteur
WO 97/48631	PCT/US97/12597	pages 1/6-6/6, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/6-6/6, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 97/50130	PCT/US97/10531	pages 1/6, 2/6, 4/6 and 6/6, drawings, replaced by new pages 1/6, 2/6, 4/6 and 6/6; due to late transmittal by the receiving Office pages 1/6, 2/6, 4/6 et 6/6, dessins, remplacées par de nouvelles pages 1/6, 2/6, 4/6 et 6/6; en raison de la transmission tardive par l'office récepteur

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VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 97/50278	PCT/US97/11894	pages 1/10-10/10, drawings, replaced by new pages 1/10-10/10; due to late transmittal by the receiving Office pages 1/10-10/10, dessins, remplacées par de nouvelles pages 1/10-10/10; en raison de la transmission tardive par l'office récepteur
WO 98/00834	PCT/US97/11683	pages 1/11-11/11, drawings, replaced by new pages 1/11-11/11; due to late transmittal by the receiving Office pages 1/11-11/11, dessins, remplacées par de nouvelles pages 1/11-11/11; en raison de la transmission tardive par l'office récepteur
WO 98/01487	PCT/EP97/03464	pages 8, 12, 18, 23, 28, 29, 32, 44, 48, 52, 57, 65, 66, 69 and 75, description, replaced by new pages 8, 12, 18, 23, 28, 29, 32, 44, 48, 52, 57, 65, 66, 69 and 75; pages 77, 79 and 82, claims, replaced by new pages 77, 79 and 82; due to late transmittal by the receiving Office pages 8, 12, 18, 23, 28, 29, 32, 44, 48, 52, 57, 65, 66, 69 et 75, description, remplacées par de nouvelles pages 8, 12, 18, 23, 28, 29, 32, 44, 48, 52, 57, 65, 66, 69 et 75; pages 77, 79 et 82, revendications, remplacées par de nouvelles pages 77, 79 et 82; en raison de la transmission tardive par l'office récepteur
WO 98/02276	PCT/US97/12572	pages 1/7-7/7, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/7-7/7, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/02545	PCT/US97/12022	pages 1/33-33/33, drawings, replaced by new pages 1/34-34/34; due to late transmittal by the receiving Office pages 1/33-33/33, dessins, remplacées par de nouvelles pages 1/34-34/34; en raison de la transmission tardive par l'office récepteur
WO 98/04900	PCT/US97/13333	page 1/7, drawings, replaced by a new page 1/7; after rectification of obvious errors as authorized by the International Searching Authority page 1/7, dessins, remplacée par une nouvelle page 1/7; après rectification d'erreurs évidentes autorisée par l'administration chargée de la recherche internationale
WO 98/04923	PCT/US97/13489	pages 1/9-9/9, drawings, replaced by new pages 1/8-8/8; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/8-8/8; en raison de la transmission tardive par l'office récepteur
WO 98/05087	PCT/US97/13592	pages 1/14-14/14, drawings, replaced by new pages 1/14-14/14; due to late transmittal by the receiving Office pages 1/14-14/14, dessins, remplacées par de nouvelles pages 1/14-14/14; en raison de la transmission tardive par l'office récepteur
WO 98/05226	PCT/US97/13381	page 1/1, drawings, replaced by a new page 1/1; due to late transmittal by the receiving Office page 1/1, dessins, remplacée par une nouvelle page 1/1; en raison de la transmission tardive par l'office récepteur
WO 98/06100	PCT/US97/13893	pages 1/9-9/9, drawings, replaced by new pages 1/8-8/8; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/8-8/8; en raison de la transmission tardive par l'office récepteur

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CORRECTED VERSIONS OF PAMPHLETS (Continued)

VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/06304	PCT/US97/14082	pages 1/30-30/30, drawings, replaced by new pages 1/29-29/29; due to late transmittal by the receiving Office pages 1/30-30/30, dessins, remplacées par de nouvelles pages 1/29-29/29; en raison de la transmission tardive par l'office récepteur
WO 98/06417	PCT/US97/14201	pages 22-26, claims, replaced by new pages 22-26; due to late transmittal by the receiving Office pages 22-26, revendications, remplacées par de nouvelles pages 22-26; en raison de la transmission tardive par l'office récepteur
WO 98/06736	PCT/US97/14266	pages 1/2-2/2, drawings, replaced by new pages 1/2-2/2; due to late transmittal by the receiving Office pages 1/2-2/2, dessins, remplacées par de nouvelles pages 1/2-2/2; en raison de la transmission tardive par l'office récepteur
WO 98/06739	PCT/US97/14487	pages 1/7-7/7, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/7-7/7, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/06752	PCT/US97/14597	pages 1/12-12/12, drawings, replaced by new pages 1/13-13/13; due to late transmittal by the receiving Office pages 1/12-12/12, dessins, remplacées par de nouvelles pages 1/13-13/13; en raison de la transmission tardive par l'office récepteur
WO 98/06965	PCT/US97/14091	pages 1/19-19/19, drawings, replaced by new pages 1/29-29/29; due to late transmittal by the receiving Office pages 1/19-19/19, dessins, remplacées par de nouvelles pages 1/29-29/29; en raison de la transmission tardive par l'office récepteur
WO 98/07332	PCT/US97/14473	pages 1/7-7/7, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/7-7/7, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/07779	PCT/US97/14510	page 1/1, drawings, replaced by a new page 1/1 page 1/1, dessins, remplacée par une nouvelle page 1/1
WO 98/07898	PCT/US97/14591	pages 1/20-20/20, drawings, replaced by new pages 1/20-20/20; due to late transmittal by the receiving Office pages 1/20-20/20, dessins, remplacées par de nouvelles pages 1/20-20/20; en raison de la transmission tardive par l'office récepteur
WO 98/07910	PCT/US97/14861	pages 1/33-33/33, drawings, replaced by new pages 1/32-32/32; due to late transmittal by the receiving Office pages 1/33-33/33, dessins, remplacées par de nouvelles pages 1/32-32/32; en raison de la transmission tardive par l'office récepteur
WO 98/07974	PCT/SE97/01378	pages 1/2-2/2, drawings, added pages 1/2-2/2, dessins, ajoutées
WO 98/08307	PCT/US97/14748	pages 1/13-13/13, drawings, replaced by new pages 1/13-13/13; due to late transmittal by the receiving Office pages 1/13-13/13, dessins, remplacées par de nouvelles pages 1/13-13/13; en raison de la transmission tardive par l'office récepteur

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CORRECTED VERSIONS OF PAMPHLETS (Continued)

VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/08595	PCT/US97/16488	pages 1/19-19/19, drawings, replaced by new pages 1/14-14/14; due to late transmittal by the receiving Office pages 1/19-19/19, dessins, remplacées par de nouvelles pages 1/14-14/14; en raison de la transmission tardive par l'office récepteur
WO 98/08732	PCT/US97/14987	pages 1/20-20/20, drawings, replaced by new pages 1/19-19/19; due to late transmittal by the receiving Office pages 1/20-20/20, dessins, remplacées par de nouvelles pages 1/19-19/19; en raison de la transmission tardive par l'office récepteur
WO 98/09568	PCT/US97/15392	pages 1/4-4/4, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/4-4/4, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 98/09635	PCT/US97/17322	pages 1/9-9/9, drawings, replaced by new pages 1/12-12/12 pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/12-12/12
WO 98/09844	PCT/EP97/04671	pages 1/3-3/3, drawings, replaced by new pages 1/3-3/3; due to late transmittal by the receiving Office pages 1/3-3/3, dessins, remplacées par de nouvelles pages 1/3-3/3; en raison de la transmission tardive par l'office récepteur
WO 98/10086	PCT/US97/15691	pages 1/8-8/8, drawings, replaced by new pages 1/8-8/8; due to late transmittal by the receiving Office pages 1/8-8/8, dessins, remplacées par de nouvelles pages 1/8-8/8; en raison de la transmission tardive par l'office récepteur
WO 98/10361	PCT/US97/15492	pages 121-147, description, replaced by new pages 121-160; pages 148-176, claims, replaced by new pages 161-194; pages 50/115 and 74/115, drawings, replaced by new pages 50/115 and 74/115; due to late transmittal by the receiving Office pages 121-147, description, remplacées par de nouvelles pages 121-160; pages 148-176, revendications, remplacées par de nouvelles pages 161-194; pages 50/115 et 74/115, dessins, remplacées par de nouvelles pages 50/115 et 74/115; en raison de la transmission tardive par l'office récepteur
WO 98/10767	PCT/US97/16145	pages 1-94, description, replaced by new pages 1-82; pages 95-111, claims, replaced by new pages 83-97; pages 1/6-6/6, drawings, replaced by new pages 1/6-6/6; due to late transmittal by the receiving Office pages 1-94, description, remplacées par de nouvelles pages 1-82; pages 95-111, revendications, remplacées par de nouvelles pages 83-97; pages 1/6-6/6, dessins, remplacées par de nouvelles pages 1/6-6/6; en raison de la transmission tardive par l'office récepteur
WO 98/10796	PCT/US97/16074	pages 1/9-9/9, drawings, replaced by new pages 1/9-9/9; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 98/10967	PCT/US97/13697	page 1, description, replaced by a new page 1; due to late transmittal by the receiving Office page 1, description, remplacée par une nouvelle page 1; en raison de la transmission tardive par l'office récepteur

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VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/10929	PCT/US97/13392	pages 1/5-5/5, drawings, replaced by new pages 1/5-5/5; due to late transmittal by the receiving Office pages 1/5-5/5, dessins, remplacées par de nouvelles pages 1/5-5/5; en raison de la transmission tardive par l'office récepteur
WO 98/11206	PCT/US97/16603	pages 50-59, description, replaced by new pages 50-59; due to late transmittal by the receiving Office pages 50-59, description, remplacées par de nouvelles pages 50-59; en raison de la transmission tardive par l'office récepteur
WO 98/11225	PCT/GB97/02479	page 19, description, replaced by a new page 19; after rectification of obvious errors as authorized by the International Searching Authority page 19, description, remplacée par une nouvelle page 19; après rectification d'erreurs évidentes autorisée par l'administration chargée de la recherche internationale
WO 98/11231	PCT/US97/16097	pages 1/15-5/15 and 7/15-15/15, drawings, replaced by new pages 1/26-13/26 and 15/26-26/26; page 6/15, drawings, renumbered as page 14/26; due to late transmittal by the receiving Office pages 1/15-5/15 et 7/15-15/15, dessins, remplacées par de nouvelles pages 1/26-13/26 et 15/26-26/26; page 6/15, dessins, renumérotée 14/26; en raison de la transmission tardive par l'office récepteur
WO 98/11363	PCT/US97/16006	pages 3/9-9/9, drawings, replaced by new pages 3/9-9/9; due to late transmittal by the receiving Office pages 3/9-9/9, dessins, remplacées par de nouvelles pages 3/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 98/11847	PCT/US97/16737	pages 1/12-12/12, drawings, replaced by new pages 1/12-12/12; due to late transmittal by the receiving Office pages 1/12-12/12, dessins, remplacées par de nouvelles pages 1/12-12/12; en raison de la transmission tardive par l'office récepteur
WO 98/11980	PCT/US97/16898	pages 1/9-9/9, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/12051	PCT/US97/16572	pages 1/7-7/7, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/7-7/7, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/12100	PCT/US97/17070	pages 1/5-5/5, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/5-5/5, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 98/12527	PCT/US97/16870	pages 1/11-11/11, drawings, replaced by new pages 1/11-11/11; due to late transmittal by the receiving Office pages 1/11-11/11, dessins, remplacées par de nouvelles pages 1/11-11/11; en raison de la transmission tardive par l'office récepteur

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VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/13156	PCT/US97/17367	pages 1/7-7/7, drawings, replaced by new pages 1/11-11/11; due to late transmittal by the receiving Office pages 1/7-7/7, dessins, remplacées par de nouvelles pages 1/11-11/11; en raison de la transmission tardive par l'office récepteur
WO 98/13295	PCT/US97/17758	pages 1/3-3/3, drawings, replaced by new pages 1/3-3/3; due to late transmittal by the receiving Office pages 1/3-3/3, dessins, remplacées par de nouvelles pages 1/3-3/3; en raison de la transmission tardive par l'office récepteur
WO 98/13491	PCT/US97/17048	pages 1/14-14/14, drawings, replaced by new pages 1/20-20/20; due to late transmittal by the receiving Office pages 1/14-14/14, dessins, remplacées par de nouvelles pages 1/20-20/20; en raison de la transmission tardive par l'office récepteur
WO 98/13508	PCT/US97/17143	pages 1/6-6/6, drawings, replaced by new pages 1/7-7/7; due to late transmittal by the receiving Office pages 1/6-6/6, dessins, remplacées par de nouvelles pages 1/7-7/7; en raison de la transmission tardive par l'office récepteur
WO 98/13511	PCT/US97/17049	pages 1/4-4/4, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/4-4/4, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 98/13553	PCT/US97/17247	pages 1/4-4/4, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/4-4/4, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 98/13756	PCT/US97/16884	pages 1/11-11/11, drawings, replaced by new pages 1/10-10/10; due to late transmittal by the receiving Office pages 1/11-11/11, dessins, remplacées par de nouvelles pages 1/10-10/10; en raison de la transmission tardive par l'office récepteur
WO 98/13973	PCT/US97/17255	pages 1/9-9/9, drawings, replaced by new pages 1/9-9/9; due to late transmittal by the receiving Office pages 1/9-9/9, dessins, remplacées par de nouvelles pages 1/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 98/14055	PCT/US97/13715	pages 1/6-6/6, drawings, replaced by new pages 1/6-6/6; due to late transmittal by the receiving Office pages 1/6-6/6, dessins, remplacées par de nouvelles pages 1/6-6/6; en raison de la transmission tardive par l'office récepteur
WO 98/14417	PCT/US97/17844	page 1/1, drawings, replaced by a new page 1/1; due to late transmittal by the receiving Office page 1/1, dessins, remplacée par une nouvelle page 1/1; en raison de la transmission tardive par l'office récepteur
WO 98/14458	PCT/EP97/05383	page 7, description, replaced by a new page 7 page 7, description, remplacée par une nouvelle page 7

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CORRECTED VERSIONS OF PAMPHLETS (Continued)

VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/14481	PCT/US97/17849	pages 1/15-15/15, drawings, replaced by new pages 1/15-15/15; due to late transmittal by the receiving Office pages 1/15-15/15, dessins, remplacées par de nouvelles pages 1/15-15/15; en raison de la transmission tardive par l'office récepteur
WO 98/14613	PCT/US97/17756	pages 1/26-26/26, drawings, replaced by new pages 1/24-24/24; due to late transmittal by the receiving Office pages 1/26-26/26, dessins, remplacées par de nouvelles pages 1/24-24/24; en raison de la transmission tardive par l'office récepteur
WO 98/14794	PCT/US97/17325	pages 1/7 and 3/7, drawings, replaced by new pages 1/7 and 3/7; due to late transmittal by the receiving Office pages 1/7 et 3/7, dessins, remplacées par de nouvelles pages 1/7 et 3/7; en raison de la transmission tardive par l'office récepteur
WO 98/14810	PCT/US97/17451	pages 1/21-21/21, drawings, replaced by new pages 1/21-21/21; due to late transmittal by the receiving Office pages 1/21-21/21, dessins, remplacées par de nouvelles pages 1/21-21/21; en raison de la transmission tardive par l'office récepteur
WO 98/14838	PCT/US97/17468	pages 1-38, description, replaced by new pages 1-38; pages 39-58, claims, replaced by new pages 39-58; pages 1/13-13/13, drawings, replaced by new pages 1/13-13/13; due to late transmittal by the receiving Office pages 1-38, description, remplacées par de nouvelles pages 1-38; pages 39-58, revendications, remplacées par de nouvelles pages 39-58; pages 1/13-13/13, dessins, remplacées par de nouvelles pages 1/13-13/13; en raison de la transmission tardive par l'office récepteur
WO 98/14903	PCT/US97/17667	pages 116-139, claims, replaced by new pages 116-139; due to late transmittal by the receiving Office pages 116-139, revendications, remplacées par de nouvelles pages 116-139; en raison de la transmission tardive par l'office récepteur
WO 98/15410	PCT/US97/18173	pages 1/2-2/2, drawings, replaced by new pages 1/2-2/2; due to late transmittal by the receiving Office pages 1/2-2/2, dessins, remplacées par de nouvelles pages 1/2-2/2; en raison de la transmission tardive par l'office récepteur
WO 98/15624	PCT/US97/18261	pages 4, 5 and 7, description, replaced by new pages 4, 5 and 7; page 98, claims, replaced by a new page 98; pages 1/15-15/15, drawings, replaced by new pages 1/18-18/18; after rectification of obvious errors as authorized by the International Searching Authority pages 4, 5 et 7, description, remplacées par de nouvelles pages 4, 5 et 7; page 98, revendications, remplacée par une nouvelle page 98; pages 1/15-15/15, dessins, remplacées par de nouvelles pages 1/18-18/18; après rectification d'erreurs évidentes autorisée par l'administration chargée de la recherche internationale

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CORRECTED VERSIONS OF PAMPHLETS (Continued)

VERSIONS CORRIGÉES DE BROCHURES (Suite)

International Publication Numbers **Numéros de publication internationale**	**International Application Numbers** **Numéros des demandes internationales**	**Corrections**
WO 98/15855	PCT/US97/18038	pages 1-12, description, replaced by new pages 1-12; pages 13-15, claims, replaced by new pages 13-15; pages 1/2-2/2, drawings, replaced by new pages 1/2-2/2; due to late transmittal by the receiving Office pages 1-12, description, remplacées par de nouvelles pages 1-12; pages 13-15, revendications, remplacées par de nouvelles pages 13-15; pages 1/2-2/2, dessins, remplacées par de nouvelles pages 1/2-2/2; en raison de la transmission tardive par l'office récepteur
WO 98/15947	PCT/US97/18108	pages 1/10-10/10, drawings, replaced by new pages 1/10-10/10; due to late transmittal by the receiving Office pages 1/10-10/10, dessins, remplacées par de nouvelles pages 1/10-10/10; en raison de la transmission tardive par l'office récepteur
WO 98/16241	PCT/US97/18331	pages 1/14-14/14, drawings, replaced by new pages 1/9-9/9; due to late transmittal by the receiving Office pages 1/14-14/14, dessins, remplacées par de nouvelles pages 1/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 98/16628	PCT/US97/18483	pages 1/10-10/10, drawings, replaced by new pages 1/12-12/12; due to late transmittal by the receiving Office pages 1/10-10/10, dessins, remplacées par de nouvelles pages 1/12-12/12; en raison de la transmission tardive par l'office récepteur
WO 98/17389	PCT/US97/19106	pages 1/20-20/20, drawings, replaced by new pages 1/20-20/20; due to late transmittal by the receiving Office pages 1/20-20/20, dessins, remplacées par de nouvelles pages 1/20-20/20; en raison de la transmission tardive par l'office récepteur
WO 98/18139	PCT/US97/18666	pages 1/4-4/4, drawings, replaced by new pages 1/4-4/4; due to late transmittal by the receiving Office pages 1/4-4/4, dessins, remplacées par de nouvelles pages 1/4-4/4; en raison de la transmission tardive par l'office récepteur
WO 98/19846	PCT/CA97/00827	pages 1/10-10/10, drawings, replaced by new pages 1/9-9/9; due to late transmittal by the receiving Office pages 1/10-10/10, dessins, remplacées par de nouvelles pages 1/9-9/9; en raison de la transmission tardive par l'office récepteur
WO 98/20013	PCT/EP97/06184	pages 1/3-3/3, drawings, replaced by new pages 1/3-3/3; due to late transmittal by the receiving Office pages 1/3-3/3, dessins, remplacées par de nouvelles pages 1/3-3/3; en raison de la transmission tardive par l'office récepteur

CORRECTED VERSION OF A PAMPHLET FRONT PAGE

VERSION CORRIGÉE DE LA PAGE DE COUVERTURE D'UNE BROCHURE

A corrected front page of the pamphlet, identified below by its international publication number, has been published on the same date as the present issue of the PCT Gazette.

Une version corrigée de la page de couverture de la brochure, identifiée ci-dessous par son numéro de publication internationale, a été publiée à la date de parution du présent numéro de la Gazette du PCT.

International Publication Number **Numéro de publication internationale**	**International Application Number** **Numéro de la demande internationale**	**Correction**
WO 97/35439	PCT/US97/05174	revised abstract received by the International Bureau after completion of the technical preparations for international publication abrégé révisé reçu par le Bureau international après achèvement de la préparation technique en vue de la publication internationale

ANNOUNCEMENT OF THE WITHDRAWAL OF A PRIORITY CLAIM AFTER COMPLETION OF THE TECHNICAL PREPARATIONS FOR INTERNATIONAL PUBLICATION

ANNONCE DU RETRAIT D'UNE REVENDICATION DE PRIORITÉ APRÈS ACHÈVEMENT DE LA PRÉPARATION TECHNIQUE DE LA PUBLICATION INTERNATIONALE

The priority claim made in relation to the international application indicated below has been withdrawn, under Rule 90bis.3, after completion of the technical preparations for international publication.

La revendication de priorité effectuée dans la demande internationale indiquée ci-dessous a été retirée en vertu de la règle 90bis.3, après l'achèvement de la préparation technique de la publication internationale.

International Application Number **Numéro de la demande internationale**	**International Publication Number** **Numéro de publication internationale**	**First International Patent Classification Symbol** **Premier symbole de la classification internationale des brevets**	**Priority Application Number** **Numéro de la demande prioritaire**	**Priority Date** **Date de priorité**	**Priority Country** **Pays de priorité**
PCT/AU96/00728	WO 97/18026	B01D 29/66	PN 6596	16 November 1995 (16.11.95) 16 novembre 1995 (16.11.95)	AU

INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/AT97/00215	WO 98/16572	–	PCT/BR97/00062	WO 98/18982	–
PCT/AT97/00220	WO 98/17551	–	PCT/CA97/00420	WO 98/23903	–
PCT/AT97/00222	WO 98/17587	–	PCT/CA97/00728	WO 98/14445	–
PCT/AT97/00223	WO 98/17833	–	PCT/CA97/00755	WO 98/16320	–
PCT/AT97/00224	WO 98/17832	–	PCT/CA97/00768	WO 98/17823	–
PCT/AT97/00228	WO 98/18696	–	PCT/CA97/00769	WO 98/16316	–
PCT/AT97/00229	WO 98/18357	–	PCT/CA97/00774	WO 98/17784	–
PCT/AU97/00302	WO 98/24229	–	PCT/CA97/00777	WO 98/17965	–
PCT/AU97/00483	WO 98/19955	–	PCT/CA97/00778	WO 98/17999	–
PCT/AU97/00701	WO 98/17749	–	PCT/CA97/00781	WO 98/17822	–
PCT/AU97/00708	WO 98/17960	–	PCT/CA97/00786	WO 98/17132	–
PCT/AU97/00715	WO 98/17290	–	PCT/CA97/00789	WO 98/17144	–
PCT/AU97/00720	WO 98/19281	–	PCT/CA97/00790	WO 98/17656	–
PCT/AU97/00721	WO 98/18918	–	PCT/CA97/00794	WO 98/17284	–
PCT/AU97/00724	WO 98/19273	–	PCT/CA97/00795	WO 98/18971	–
PCT/AU97/00725	WO 98/19274	–	PCT/CA97/00800	WO 98/18332	–
PCT/AU97/00726	WO 98/18370	–	PCT/CA97/00808	WO 98/20449	–
PCT/AU97/00727	WO 98/20283	–	PCT/CA97/00819	WO 98/20325	–
PCT/AU97/00734	WO 98/19536	–	PCT/CA97/00848	WO 98/21361	–
PCT/AU97/00750	WO 98/20215	–	PCT/CA97/00892	WO 98/23299	–
PCT/AU97/00755	WO 98/19872	–	PCT/CA97/00914	WO 98/23175	–
PCT/AU97/00759	WO 98/20949	–	PCT/CH97/00337	WO 98/17461	–
PCT/AU97/00761	WO 98/21013	–	PCT/CH97/00368	WO 98/16231	–
PCT/AU97/00762	WO 98/21067	–	PCT/CH97/00369	WO 98/15220	–
PCT/AU97/00765	WO 98/20947	–	PCT/CH97/00377	WO 98/15465	–
PCT/AU97/00769	WO 98/21432	–	PCT/CH97/00381	WO 98/16673	–
PCT/AU97/00800	WO 98/23979	–	PCT/CH97/00382	WO 98/15310	–
PCT/AU97/00803	WO 98/23849	–	PCT/CH97/00383	WO 98/15971	–
PCT/AU97/00807	WO 98/23357	–	PCT/CH97/00403	WO 98/17987	–
PCT/BE97/00125	WO 98/18874	–	PCT/CH97/00406	WO 98/20802	–
PCT/BE97/00130	WO 98/23705	–	PCT/CN96/00094	WO 98/17348	–
PCT/BR96/00046	WO 98/16822	–	PCT/CN97/00001	WO 97/25054	–
PCT/BR97/00050	WO 98/23352	–	PCT/CN97/00099	WO 98/18373	–
PCT/BR97/00059	WO 98/18007	–	PCT/CZ97/00039	WO 98/20313	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/DE96/02271	WO 98/23476	–	PCT/DE97/02428	WO 98/17572	–
PCT/DE97/01935	WO 98/17023	–	PCT/DE97/02437	WO 98/21860	–
PCT/DE97/01967	WO 98/15428	–	PCT/DE97/02439	WO 98/18003	–
PCT/DE97/02143	WO 98/21019	–	PCT/DE97/02452	WO 98/17454	–
PCT/DE97/02198	WO 98/23859	–	PCT/DE97/02453	WO 98/18171	–
PCT/DE97/02218	WO 98/18036	–	PCT/DE97/02467	WO 98/18055	–
PCT/DE97/02227	WO 98/15138	–	PCT/DE97/02480	WO 98/19360	–
PCT/DE97/02243	WO 98/24280	–	PCT/DE97/02481	WO 98/19451	–
PCT/DE97/02251	WO 98/15498	–	PCT/DE97/02495	WO 98/20699	–
PCT/DE97/02277	WO 98/16624	–	PCT/DE97/02504	WO 98/19484	–
PCT/DE97/02309	WO 98/15665	–	PCT/DE97/02523	WO 98/18628	–
PCT/DE97/02318	WO 98/24010	–	PCT/DE97/02534	WO 98/18428	–
PCT/DE97/02320	WO 98/16953	–	PCT/DE97/02543	WO 98/23022	–
PCT/DE97/02323	WO 98/18275	–	PCT/DE97/02550	WO 98/24060	–
PCT/DE97/02327	WO 98/15998	–	PCT/DE97/02555	WO 98/19093	–
PCT/DE97/02343	WO 98/17073	–	PCT/DE97/02573	WO 98/19202	–
PCT/DE97/02346	WO 98/16824	–	PCT/DE97/02589	WO 98/20624	–
PCT/DE97/02349	WO 98/24170	–	PCT/DE97/02590	WO 98/19591	–
PCT/DE97/02350	WO 98/24239	–	PCT/DE97/02600	WO 98/24039	–
PCT/DE97/02351	WO 98/18276	–	PCT/DE97/02629	WO 98/23937	–
PCT/DE97/02357	WO 98/20579	–	PCT/DE97/02671	WO 98/23917	–
PCT/DE97/02363	WO 98/15933	–	PCT/DE97/02677	WO 98/21079	–
PCT/DE97/02366	WO 98/17415	–	PCT/DE97/02680	WO 98/24171	–
PCT/DE97/02372	WO 98/16536	–	PCT/DE97/02695	WO 98/24137	–
PCT/DE97/02375	WO 98/17398	–	PCT/DE97/02703	WO 98/24009	–
PCT/DE97/02384	WO 98/17885	–	PCT/DE97/02716	WO 98/23541	–
PCT/DE97/02386	WO 98/16877	–	PCT/DE97/02736	WO 98/23734	–
PCT/DE97/02388	WO 98/17831	–	PCT/DE97/02737	WO 98/23986	–
PCT/DE97/02389	WO 98/18056	–	PCT/DE97/02740	WO 98/23934	–
PCT/DE97/02393	WO 98/17571	–	PCT/DE97/02751	WO 98/23935	–
PCT/DE97/02400	WO 98/17122	–	PCT/DE97/02767	WO 98/24051	–
PCT/DE97/02411	WO 98/18536	–	PCT/DK96/00429	WO 98/15788	–
PCT/DE97/02414	WO 98/18058	–	PCT/DK97/00334	WO 98/09860	–
PCT/DE97/02421	WO 98/21484	–	PCT/DK97/00362	WO 98/10149	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/DK97/00404	WO 98/15312	–	PCT/EP97/05201	WO 98/16564	–
PCT/DK97/00405	WO 98/13957	–	PCT/EP97/05209	WO 98/12912	–
PCT/DK97/00407	WO 98/13268	–	PCT/EP97/05275	WO 98/13255	–
PCT/DK97/00432	WO 98/15806	–	PCT/EP97/05278	WO 98/16949	–
PCT/DK97/00453	WO 98/17915	–	PCT/EP97/05312	WO 98/16363	–
PCT/DK97/00471	WO 98/23501	–	PCT/EP97/05313	WO 98/16578	–
PCT/DK97/00475	WO 98/19165	–	PCT/EP97/05365	WO 98/14682	–
PCT/DK97/00478	WO 98/18771	–	PCT/EP97/05383	WO 98/14458	–
PCT/DK97/00479	WO 98/18772	–	PCT/EP97/05407	WO 98/18155	–
PCT/DK97/00480	WO 98/18773	–	PCT/EP97/05409	WO 98/24114	–
PCT/DK97/00481	WO 98/18774	–	PCT/EP97/05413	WO 98/18156	–
PCT/DK97/00482	WO 98/18775	–	PCT/EP97/05427	WO 98/14309	–
PCT/DK97/00483	WO 98/18776	–	PCT/EP97/05445	WO 98/15799	–
PCT/DK97/00484	WO 98/18777	–	PCT/EP97/05448	WO 98/14219	–
PCT/DK97/00485	WO 98/18778	–	PCT/EP97/05454	WO 98/17825	–
PCT/DK97/00486	WO 98/18779	–	PCT/EP97/05458	WO 98/16776	–
PCT/EP96/04359	WO 98/15407	–	PCT/EP97/05468	WO 98/15660	–
PCT/EP96/04427	WO 98/16356	–	PCT/EP97/05482	WO 98/15557	–
PCT/EP96/05218	WO 98/24093	–	PCT/EP97/05502	WO 98/15784	–
PCT/EP96/05291	WO 98/23878	–	PCT/EP97/05504	WO 98/21258	–
PCT/EP97/00005	WO 98/15907	–	PCT/EP97/05505	WO 98/21259	–
PCT/EP97/00466	WO 98/23526	–	PCT/EP97/05506	WO 98/21260	–
PCT/EP97/03633	WO 98/23201	–	PCT/EP97/05513	WO 98/16718	–
PCT/EP97/04021	WO 98/16331	–	PCT/EP97/05514	WO 98/16595	–
PCT/EP97/04141	WO 98/18100	–	PCT/EP97/05530	WO 98/17668	–
PCT/EP97/04416	WO 98/18278	–	PCT/EP97/05548	WO 98/15236	–
PCT/EP97/04523	WO 98/20310	–	PCT/EP97/05567	WO 98/15433	–
PCT/EP97/04650	WO 98/16838	–	PCT/EP97/05583	WO 98/15650	–
PCT/EP97/04861	WO 98/15432	–	PCT/EP97/05587	WO 98/15491	–
PCT/EP97/04940	WO 98/19897	–	PCT/EP97/05588	WO 98/23265	–
PCT/EP97/04969	WO 98/20688	–	PCT/EP97/05589	WO 98/17305	–
PCT/EP97/05122	WO 98/14815	–	PCT/EP97/05608	WO 98/23266	–
PCT/EP97/05134	WO 98/19805	–	PCT/EP97/05609	WO 98/23238	–
PCT/EP97/05146	WO 98/14345	–	PCT/EP97/05612	WO 98/23922	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/EP97/05616	WO 98/15172	–	PCT/EP97/05859	WO 98/18126	–
PCT/EP97/05619	WO 98/16814	–	PCT/EP97/05863	WO 98/17250	–
PCT/EP97/05624	WO 98/16901	–	PCT/EP97/05870	WO 98/23860	–
PCT/EP97/05629	WO 98/16146	–	PCT/EP97/05877	WO 98/18877	–
PCT/EP97/05648	WO 98/16340	–	PCT/EP97/05879	WO 98/17876	–
PCT/EP97/05651	WO 98/17488	–	PCT/EP97/05884	WO 98/19993	–
PCT/EP97/05658	WO 98/16346	–	PCT/EP97/05885	WO 98/18378	–
PCT/EP97/05663	WO 98/16589	–	PCT/EP97/05888	WO 98/18996	–
PCT/EP97/05680	WO 98/20452	–	PCT/EP97/05897	WO 98/18943	–
PCT/EP97/05684	WO 98/18014	–	PCT/EP97/05899	WO 98/19454	–
PCT/EP97/05685	WO 98/18556	–	PCT/EP97/05907	WO 98/23261	–
PCT/EP97/05688	WO 98/18555	–	PCT/EP97/05909	WO 98/18805	–
PCT/EP97/05702	WO 98/22200	–	PCT/EP97/05910	WO 98/18587	–
PCT/EP97/05722	WO 98/19584	–	PCT/EP97/05920	WO 98/17277	–
PCT/EP97/05732	WO 98/17971	–	PCT/EP97/05921	WO 98/19553	–
PCT/EP97/05736	WO 98/18093	–	PCT/EP97/05922	WO 98/17778	–
PCT/EP97/05740	WO 98/17612	–	PCT/EP97/05926	WO 98/20227	–
PCT/EP97/05743	WO 98/18795	–	PCT/EP97/05931	WO 98/17765	–
PCT/EP97/05751	WO 98/18899	–	PCT/EP97/05936	WO 98/18718	–
PCT/EP97/05752	WO 98/18868	–	PCT/EP97/05941	WO 98/19399	–
PCT/EP97/05771	WO 98/18678	–	PCT/EP97/05958	WO 98/19538	–
PCT/EP97/05772	WO 98/17866	–	PCT/EP97/05970	WO 98/18528	–
PCT/EP97/05778	WO 98/19204	–	PCT/EP97/05996	WO 98/20450	–
PCT/EP97/05793	WO 98/18885	–	PCT/EP97/06006	WO 98/18736	–
PCT/EP97/05814	WO 98/18295	–	PCT/EP97/06009	WO 98/19952	–
PCT/EP97/05820	WO 98/20862	–	PCT/EP97/06015	WO 98/18432	–
PCT/EP97/05826	WO 98/19537	–	PCT/EP97/06017	WO 98/20052	–
PCT/EP97/05830	WO 98/18977	–	PCT/EP97/06023	WO 98/21794	–
PCT/EP97/05845	WO 98/18648	–	PCT/EP97/06031	WO 98/20297	–
PCT/EP97/05848	WO 98/18474	–	PCT/EP97/06033	WO 98/20195	–
PCT/EP97/05851	WO 98/23497	–	PCT/EP97/06042	WO 98/21849	–
PCT/EP97/05853	WO 98/17596	–	PCT/EP97/06047	WO 98/21464	–
PCT/EP97/05854	WO 98/18791	–	PCT/EP97/06049	WO 98/21058	–
PCT/EP97/05855	WO 98/20012	–	PCT/EP97/06060	WO 98/20228	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**	**International Application Numbers** **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**
PCT/EP97/06072	WO 98/23164	–	PCT/EP97/06367	WO 98/23598	–
PCT/EP97/06079	WO 98/24008	–	PCT/EP97/06368	WO 98/23605	–
PCT/EP97/06082	WO 98/20859	–	PCT/EP97/06378	WO 98/16879	–
PCT/EP97/06085	WO 98/20845	–	PCT/EP97/06384	WO 98/23253	–
PCT/EP97/06108	WO 98/20493	–	PCT/EP97/06385	WO 98/22242	–
PCT/EP97/06111	WO 98/23515	–	PCT/EP97/06386	WO 98/23884	–
PCT/EP97/06119	WO 98/23676	–	PCT/EP97/06392	WO 98/23600	–
PCT/EP97/06136	WO 98/21161	–	PCT/EP97/06393	WO 98/23678	–
PCT/EP97/06144	WO 98/23005	–	PCT/EP97/06395	WO 98/23262	–
PCT/EP97/06148	WO 98/23001	–	PCT/EP97/06397	WO 98/21098	–
PCT/EP97/06152	WO 98/23002	–	PCT/EP97/06415	WO 98/23652	–
PCT/EP97/06154	WO 98/23010	–	PCT/EP97/06417	WO 98/23390	–
PCT/EP97/06180	WO 98/19702	–	PCT/EP97/06425	WO 98/23570	–
PCT/EP97/06181	WO 98/22591	–	PCT/EP97/06431	WO 98/23722	–
PCT/EP97/06182	WO 98/23258	–	PCT/EP97/06434	WO 98/23495	–
PCT/EP97/06195	WO 98/20233	–	PCT/EP97/06447	WO 98/23275	–
PCT/EP97/06197	WO 98/20995	–	PCT/EP97/06450	WO 98/23277	–
PCT/EP97/06204	WO 98/21790	–	PCT/EP97/06486	WO 98/23692	–
PCT/EP97/06206	WO 98/21787	–	PCT/EP97/06495	WO 98/23434	–
PCT/EP97/06208	WO 98/21495	–	PCT/EP97/06523	WO 98/23816	–
PCT/EP97/06221	WO 98/20909	–	PCT/EP97/06578	WO 98/23622	–
PCT/EP97/06257	WO 98/20856	–	PCT/EP97/06582	WO 98/23961	–
PCT/EP97/06271	WO 98/22302	–	PCT/EP97/06583	WO 98/23955	–
PCT/EP97/06275	WO 98/23651	–	PCT/EP97/06648	WO 98/23525	–
PCT/EP97/06290	WO 98/23649	–	PCT/EP97/06668	WO 98/23740	–
PCT/EP97/06291	WO 98/23688	–	PCT/EP97/06938	WO 98/21373	–
PCT/EP97/06292	WO 98/23581	–	PCT/FI96/00520	WO 98/14658	–
PCT/EP97/06295	WO 98/21616	–	PCT/FI96/00521	WO 98/14683	–
PCT/EP97/06311	WO 98/21193	–	PCT/FI97/00524	WO 98/10540	–
PCT/EP97/06347	WO 98/22726	–	PCT/FI97/00529	WO 98/09707	–
PCT/EP97/06354	WO 98/22713	–	PCT/FI97/00549	WO 98/12678	–
PCT/EP97/06357	WO 98/22763	–	PCT/FI97/00570	WO 98/14020	–
PCT/EP97/06362	WO 98/23985	–	PCT/FI97/00607	WO 98/16078	–
PCT/EP97/06363	WO 98/24178	–	PCT/FI97/00609	WO 98/16052	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/FI97/00610	WO 98/16079	–	PCT/FR97/01987	WO 98/24026	–
PCT/FI97/00611	WO 98/16037	–	PCT/FR97/02041	WO 98/21374	–
PCT/FI97/00612	WO 98/18227	–	PCT/FR97/02065	WO 98/22077	–
PCT/FI97/00613	WO 98/18267	–	PCT/FR97/02075	WO 98/22693	–
PCT/FI97/00630	WO 98/18199	–	PCT/FR97/02092	WO 98/23573	–
PCT/FI97/00631	WO 98/18197	–	PCT/FR97/02100	WO 98/24057	–
PCT/FI97/00632	WO 98/18198	–	PCT/FR97/02120	WO 98/23332	–
PCT/FI97/00717	WO 98/23394	–	PCT/FR97/02162	WO 98/23530	–
PCT/FI97/00723	WO 98/23514	–	PCT/GB97/00215	WO 97/27380	–
PCT/FR97/01695	WO 98/13715	–	PCT/GB97/02441	WO 98/16215	–
PCT/FR97/01702	WO 98/21998	–	PCT/GB97/02481	WO 98/13838	–
PCT/FR97/01745	WO 98/15848	–	PCT/GB97/02633	WO 98/13275	–
PCT/FR97/01805	WO 98/16478	–	PCT/GB97/02640	WO 98/15921	–
PCT/FR97/01820	WO 98/16740	–	PCT/GB97/02661	WO 98/13684	–
PCT/FR97/01831	WO 98/16484	–	PCT/GB97/02687	WO 98/19246	–
PCT/FR97/01835	WO 98/16780	–	PCT/GB97/02734	WO 98/15652	–
PCT/FR97/01858	WO 98/17599	–	PCT/GB97/02735	WO 98/17374	–
PCT/FR97/01861	WO 98/17378	–	PCT/GB97/02745	WO 98/17692	–
PCT/FR97/01865	WO 98/17367	–	PCT/GB97/02747	WO 98/17922	–
PCT/FR97/01869	WO 98/17158	–	PCT/GB97/02757	WO 98/15362	–
PCT/FR97/01886	WO 98/17950	–	PCT/GB97/02758	WO 98/18040	–
PCT/FR97/01894	WO 98/18308	–	PCT/GB97/02759	WO 98/19045	–
PCT/FR97/01895	WO 98/18380	–	PCT/GB97/02761	WO 98/19046	–
PCT/FR97/01902	WO 98/23246	–	PCT/GB97/02765	WO 98/17456	–
PCT/FR97/01905	WO 98/17437	–	PCT/GB97/02777	WO 98/19153	–
PCT/FR97/01908	WO 98/18317	–	PCT/GB97/02781	WO 98/16725	–
PCT/FR97/01918	WO 98/18958	–	PCT/GB97/02785	WO 98/18427	–
PCT/FR97/01937	WO 98/18369	–	PCT/GB97/02809	WO 98/17906	–
PCT/FR97/01941	WO 98/19104	–	PCT/GB97/02811	WO 98/18103	–
PCT/FR97/01947	WO 98/18360	–	PCT/GB97/02812	WO 98/17416	–
PCT/FR97/01955	WO 98/20272	–	PCT/GB97/02814	WO 98/19173	–
PCT/FR97/01966	WO 98/19967	–	PCT/GB97/02834	WO 98/16103	–
PCT/FR97/01973	WO 98/20080	–	PCT/GB97/02838	WO 98/16648	–
PCT/FR97/01981	WO 98/20384	–	PCT/GB97/02857	WO 98/17815	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/GB97/02858	WO 98/17816	–	PCT/GB97/03035	WO 98/20992	–
PCT/GB97/02860	WO 98/16535	–	PCT/GB97/03044	WO 98/20971	–
PCT/GB97/02862	WO 98/17280	–	PCT/GB97/03056	WO 98/23158	–
PCT/GB97/02865	WO 98/17930	–	PCT/GB97/03062	WO 98/20382	–
PCT/GB97/02868	WO 98/17892	–	PCT/GB97/03074	WO 98/20794	–
PCT/GB97/02869	WO 98/17893	–	PCT/GB97/03097	WO 98/21580	–
PCT/GB97/02870	WO 98/23354	–	PCT/GB97/03110	WO 98/22744	–
PCT/GB97/02883	WO 98/17383	–	PCT/GB97/03136	WO 98/22971	–
PCT/GB97/02884	WO 98/17649	–	PCT/GB97/03159	WO 98/23742	–
PCT/GB97/02885	WO 98/17648	–	PCT/GB97/03180	WO 98/24078	–
PCT/GB97/02886	WO 98/17650	–	PCT/GB97/03181	WO 98/24086	–
PCT/GB97/02896	WO 98/17216	–	PCT/GB97/03216	WO 98/23936	–
PCT/GB97/02898	WO 98/17324	–	PCT/GB97/03240	WO 98/23486	–
PCT/GB97/02901	WO 98/17262	–	PCT/GB97/03250	WO 98/24065	–
PCT/GB97/02905	WO 98/17288	–	PCT/GB97/03269	WO 98/23815	–
PCT/GB97/02907	WO 98/17661	–	PCT/GB97/03300	WO 98/24262	–
PCT/GB97/02909	WO 98/17401	–	PCT/GB97/03301	WO 98/24263	–
PCT/GB97/02918	WO 98/17812	–	PCT/GR97/00038	WO 98/19589	–
PCT/GB97/02924	WO 98/18022	–	PCT/HU97/00062	WO 98/16309	–
PCT/GB97/02925	WO 98/18039	–	PCT/HU97/00065	WO 98/17926	–
PCT/GB97/02927	WO 98/23350	–	PCT/HU97/00069	WO 98/18797	–
PCT/GB97/02928	WO 98/18318	–	PCT/HU97/00071	WO 98/18329	–
PCT/GB97/02933	WO 98/18298	–	PCT/IB97/00597	WO 98/24195	–
PCT/GB97/02935	WO 98/18387	–	PCT/IB97/00962	WO 97/49889	–
PCT/GB97/02949	WO 98/18782	–	PCT/IB97/01202	WO 98/16140	–
PCT/GB97/02950	WO 98/19226	–	PCT/IB97/01263	WO 98/18017	–
PCT/GB97/02962	WO 98/19219	–	PCT/IB97/01284	WO 98/18181	US
PCT/GB97/02969	WO 98/18934	–	PCT/IB97/01286	WO 98/18041	–
PCT/GB97/02977	WO 98/18677	–	PCT/IB97/01323	WO 98/16130	–
PCT/GB97/02980	WO 98/19073	–	PCT/IB97/01329	WO 98/17386	–
PCT/GB97/02983	WO 98/18909	–	PCT/IB97/01349	WO 98/20584	–
PCT/GB97/03013	WO 98/20355	–	PCT/IB97/01362	WO 98/20240	–
PCT/GB97/03031	WO 98/21383	–	PCT/IB97/01367	WO 98/21184	–
PCT/GB97/03033	WO 98/21188	–	PCT/IB97/01368	WO 98/23593	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**	**International Application Numbers** **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**
PCT/IB97/01377	WO 98/15826	–	PCT/JP97/03125	WO 98/09945	–
PCT/IB97/01393	WO 98/23613	–	PCT/JP97/03236	WO 98/12175	–
PCT/IB97/01423	WO 98/20360	–	PCT/JP97/03323	WO 98/13515	–
PCT/IB97/01465	WO 98/23603	–	PCT/JP97/03338	WO 98/24021	–
PCT/IB97/01468	WO 98/24045	–	PCT/JP97/03342	WO 98/12195	–
PCT/IB97/01474	WO 98/24149	–	PCT/JP97/03357	WO 98/12715	–
PCT/IB97/01627	WO 98/20124	–	PCT/JP97/03392	WO 98/13389	–
PCT/IE97/00071	WO 98/18490	–	PCT/JP97/03418	WO 98/15076	–
PCT/IE97/00073	WO 98/19558	–	PCT/JP97/03419	WO 98/16889	–
PCT/IL96/00162	WO 98/23973	–	PCT/JP97/03421	WO 98/14484	–
PCT/IL97/00217	WO 98/19179	–	PCT/JP97/03425	WO 98/13827	–
PCT/IL97/00292	WO 98/16739	–	PCT/JP97/03522	WO 98/14831	–
PCT/IL97/00330	WO 98/16874	–	PCT/JP97/03543	WO 98/15021	–
PCT/IL97/00336	WO 98/19815	–	PCT/JP97/03603	WO 98/16497	–
PCT/IL97/00375	WO 98/23329	–	PCT/JP97/03608	WO 98/15263	–
PCT/IL97/00392	WO 98/23211	–	PCT/JP97/03627	WO 98/15943	–
PCT/IT97/00011	WO 98/21476	–	PCT/JP97/03667	WO 98/17808	–
PCT/IT97/00241	WO 98/17527	–	PCT/JP97/03687	WO 98/23628	–
PCT/IT97/00246	WO 98/17954	–	PCT/JP97/03702	WO 98/18229	–
PCT/JP96/02740	WO 98/13206	–	PCT/JP97/03717	WO 98/17438	–
PCT/JP96/02917	WO 98/15366	–	PCT/JP97/03724	WO 98/16307	–
PCT/JP96/02918	WO 98/15367	–	PCT/JP97/03742	WO 98/16145	–
PCT/JP96/02999	WO 98/16348	–	PCT/JP97/03744	WO 98/16470	–
PCT/JP96/03448	WO 98/24027	–	PCT/JP97/03745	WO 98/17739	–
PCT/JP96/03467	WO 98/23995	–	PCT/JP97/03754	WO 98/16625	–
PCT/JP96/03468	WO 98/24081	–	PCT/JP97/03778	WO 98/17869	JP
PCT/JP96/03503	WO 98/23851	–	PCT/JP97/03779	WO 98/16787	–
PCT/JP97/01995	WO 98/12098	–	PCT/JP97/03780	WO 98/16788	–
PCT/JP97/02851	WO 98/23664	–	PCT/JP97/03781	WO 98/16789	–
PCT/JP97/03022	WO 98/08527	–	PCT/JP97/03820	WO 98/18692	–
PCT/JP97/03094	WO 98/10435	–	PCT/JP97/03845	WO 98/18170	–
PCT/JP97/03096	WO 98/24082	–	PCT/JP97/03848	WO 98/16790	–
PCT/JP97/03097	WO 98/10000	–	PCT/JP97/03959	WO 98/23399	–
PCT/JP97/03098	WO 98/09784	–	PCT/JP97/03960	WO 98/23450	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/JP97/03975	WO 98/19056	–	PCT/JP97/04374	WO 98/23594	–
PCT/JP97/04003	WO 98/20542	–	PCT/JP97/04379	WO 98/24292	–
PCT/JP97/04047	WO 98/20518	–	PCT/KR97/00166	WO 98/20578	–
PCT/JP97/04055	WO 98/19960	–	PCT/KR97/00197	WO 98/19688	–
PCT/JP97/04060	WO 98/21828	–	PCT/KR97/00199	WO 98/17614	–
PCT/JP97/04100	WO 98/21005	–	PCT/NL97/00538	WO 98/13490	–
PCT/JP97/04165	WO 98/23384	–	PCT/NL97/00555	WO 98/16443	–
PCT/JP97/04177	WO 98/24108	–	PCT/NL97/00565	WO 98/16319	–
PCT/JP97/04191	WO 98/23374	–	PCT/NL97/00623	WO 98/24113	–
PCT/JP97/04194	WO 98/22498	–	PCT/NO97/00229	WO 98/10238	–
PCT/JP97/04252	WO 98/23614	–	PCT/NO97/00270	WO 98/15349	–
PCT/JP97/04265	WO 98/23562	–	PCT/NO97/00276	WO 98/16708	–
PCT/JP97/04271	WO 98/23767	–	PCT/NO97/00277	WO 98/17941	–
PCT/JP97/04276	WO 98/23615	–	PCT/NO97/00279	WO 98/19560	–
PCT/JP97/04277	WO 98/23629	–	PCT/NO97/00288	WO 98/20797	–
PCT/JP97/04285	WO 98/23557	–	PCT/NO97/00289	WO 98/20911	–
PCT/JP97/04287	WO 98/23607	–	PCT/NZ97/00134	WO 98/15579	–
PCT/JP97/04288	WO 98/23556	–	PCT/NZ97/00135	WO 98/16430	–
PCT/JP97/04295	WO 98/23918	–	PCT/NZ97/00141	WO 98/18463	–
PCT/JP97/04299	WO 98/23768	–	PCT/NZ97/00158	WO 98/23770	–
PCT/JP97/04300	WO 98/23769	–	PCT/RU96/00364	WO 98/19601	–
PCT/JP97/04301	WO 98/23916	–	PCT/RU97/00114	WO 98/13082	–
PCT/JP97/04303	WO 98/23176	–	PCT/RU97/00150	WO 98/10442	–
PCT/JP97/04313	WO 98/24112	–	PCT/RU97/00159	WO 98/21769	–
PCT/JP97/04318	WO 98/23430	–	PCT/RU97/00215	WO 98/14158	–
PCT/JP97/04323	WO 98/23271	–	PCT/RU97/00225	WO 98/13052	–
PCT/JP97/04328	WO 98/23583	–	PCT/RU97/00238	WO 98/05054	–
PCT/JP97/04330	WO 98/23563	–	PCT/RU97/00282	WO 98/11848	–
PCT/JP97/04331	WO 98/23564	–	PCT/RU97/00292	WO 98/13817	–
PCT/JP97/04334	WO 98/23624	–	PCT/RU97/00294	WO 98/13661	–
PCT/JP97/04335	WO 98/23553	–	PCT/RU97/00298	WO 98/13446	–
PCT/JP97/04337	WO 98/23406	–	PCT/RU97/00299	WO 98/14737	–
PCT/JP97/04368	WO 98/23449	–	PCT/RU97/00302	WO 98/14899	–
PCT/JP97/04373	WO 98/23568	–	PCT/RU97/00304	WO 98/14161	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/RU97/00305	WO 98/14162	–	PCT/SE97/01865	WO 98/20308	–
PCT/RU97/00307	WO 98/14791	–	PCT/SG97/00047	WO 98/20683	–
PCT/RU97/00312	WO 98/15158	–	PCT/SG97/00054	WO 98/18593	–
PCT/RU97/00314	WO 98/14166	–	PCT/SG97/00057	WO 98/20517	–
PCT/RU97/00315	WO 98/15332	–	PCT/SG97/00058	WO 98/20604	–
PCT/RU97/00318	WO 98/15495	–	PCT/SG97/00060	WO 98/24226	–
PCT/SE97/01329	WO 98/19363	–	PCT/UA96/00016	WO 98/11722	–
PCT/SE97/01330	WO 98/19364	–	PCT/US96/14899	WO 98/12026	–
PCT/SE97/01534	WO 98/15139	–	PCT/US96/16520	WO 98/15247	–
PCT/SE97/01576	WO 98/16287	–	PCT/US96/17227	WO 98/18340	–
PCT/SE97/01635	WO 98/14772	–	PCT/US96/19081	WO 98/23707	–
PCT/SE97/01656	WO 98/14238	–	PCT/US96/19112	WO 98/23708	–
PCT/SE97/01657	WO 98/16071	–	PCT/US96/19115	WO 98/23709	–
PCT/SE97/01660	WO 98/15748	–	PCT/US96/19807	WO 97/21769	–
PCT/SE97/01674	WO 98/15227	–	PCT/US96/20059	WO 98/13041	–
PCT/SE97/01680	WO 98/15334	–	PCT/US97/01324	WO 98/18596	–
PCT/SE97/01682	WO 98/15336	–	PCT/US97/02783	WO 98/21795	–
PCT/SE97/01688	WO 98/15754	–	PCT/US97/03827	WO 98/20491	–
PCT/SE97/01697	WO 98/16416	–	PCT/US97/04446	WO 98/20055	–
PCT/SE97/01699	WO 98/17080	–	PCT/US97/04575	WO 98/21023	–
PCT/SE97/01711	WO 98/19090	–	PCT/US97/04619	WO 98/00482	–
PCT/SE97/01712	WO 98/16792	–	PCT/US97/05010	WO 98/23818	–
PCT/SE97/01723	WO 98/16690	–	PCT/US97/05450	WO 98/23694	–
PCT/SE97/01730	WO 98/20504	–	PCT/US97/05527	WO 98/23518	–
PCT/SE97/01739	WO 98/18504	–	PCT/US97/05946	WO 97/40211	–
PCT/SE97/01740	WO 98/18505	–	PCT/US97/06673	WO 98/23893	–
PCT/SE97/01756	WO 98/19003	–	PCT/US97/06674	WO 98/23407	–
PCT/SE97/01762	WO 98/17861	–	PCT/US97/06702	WO 98/16855	–
PCT/SE97/01766	WO 98/19460	–	PCT/US97/08564	WO 98/20778	–
PCT/SE97/01772	WO 98/19438	–	PCT/US97/09150	WO 97/45699	–
PCT/SE97/01806	WO 98/19155	–	PCT/US97/09239	WO 97/49607	–
PCT/SE97/01834	WO 98/19953	–	PCT/US97/09857	WO 98/07892	–
PCT/SE97/01852	WO 98/23810	–	PCT/US97/10449	WO 98/12833	–
PCT/SE97/01864	WO 98/20307	–	PCT/US97/10757	WO 98/24120	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/US97/10864	WO 98/20654	–	PCT/US97/15254	WO 98/23244	–
PCT/US97/11249	WO 97/49972	–	PCT/US97/15312	WO 98/09987	–
PCT/US97/11432	WO 98/18618	–	PCT/US97/15335	WO 98/15769	–
PCT/US97/11476	WO 98/18289	–	PCT/US97/15456	WO 98/09973	–
PCT/US97/12565	WO 98/06486	–	PCT/US97/15539	WO 98/16379	–
PCT/US97/12751	WO 98/02084	–	PCT/US97/15552	WO 98/10387	–
PCT/US97/12853	WO 98/06143	–	PCT/US97/15600	WO 98/16998	–
PCT/US97/13035	WO 98/03207	–	PCT/US97/15604	WO 98/11334	–
PCT/US97/13063	WO 98/19903	–	PCT/US97/15623	WO 98/16574	–
PCT/US97/13066	WO 98/16137	–	PCT/US97/15732	WO 98/15190	–
PCT/US97/13132	WO 98/21699	–	PCT/US97/15733	WO 98/16545	–
PCT/US97/13199	WO 98/19258	–	PCT/US97/15738	WO 98/15861	–
PCT/US97/13464	WO 98/08285	–	PCT/US97/15739	WO 98/15860	–
PCT/US97/13641	WO 98/11933	–	PCT/US97/15744	WO 98/16540	–
PCT/US97/13656	WO 98/08105	–	PCT/US97/15745	WO 98/15327	–
PCT/US97/13893	WO 98/06100	–	PCT/US97/15746	WO 98/15492	–
PCT/US97/14002	WO 98/07142	–	PCT/US97/15754	WO 98/15825	–
PCT/US97/14024	WO 98/21659	–	PCT/US97/15791	WO 98/22749	–
PCT/US97/14025	WO 98/16324	–	PCT/US97/15839	WO 98/16818	–
PCT/US97/14026	WO 98/21709	–	PCT/US97/15852	WO 98/15323	–
PCT/US97/14071	WO 98/06451	–	PCT/US97/15853	WO 98/16066	–
PCT/US97/14105	WO 98/13166	–	PCT/US97/15937	WO 98/11947	–
PCT/US97/14348	WO 98/08558	–	PCT/US97/15950	WO 98/20467	–
PCT/US97/14371	WO 98/22908	–	PCT/US97/15951	WO 98/15019	–
PCT/US97/14464	WO 98/07136	–	PCT/US97/15985	WO 98/20732	–
PCT/US97/14626	WO 98/11469	–	PCT/US97/16006	WO 98/11363	–
PCT/US97/14805	WO 98/10407	–	PCT/US97/16056	WO 98/16579	–
PCT/US97/14842	WO 98/09208	–	PCT/US97/16102	WO 98/10734	–
PCT/US97/15090	WO 98/17951	–	PCT/US97/16135	WO 98/12493	–
PCT/US97/15125	WO 98/17466	–	PCT/US97/16158	WO 98/11677	–
PCT/US97/15199	WO 98/15803	–	PCT/US97/16166	WO 98/23589	–
PCT/US97/15207	WO 98/09416	–	PCT/US97/16181	WO 98/10649	–
PCT/US97/15245	WO 98/08506	–	PCT/US97/16247	WO 98/10925	–
PCT/US97/15252	WO 98/10053	–	PCT/US97/16264	WO 98/11449	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/US97/16265	WO 98/11446	–	PCT/US97/17058	WO 98/16795	–
PCT/US97/16303	WO 98/11787	–	PCT/US97/17090	WO 98/14249	–
PCT/US97/16385	WO 98/13248	–	PCT/US97/17091	WO 98/14963	–
PCT/US97/16394	WO 98/12022	–	PCT/US97/17133	WO 98/14602	–
PCT/US97/16436	WO 98/11815	–	PCT/US97/17151	WO 98/15688	–
PCT/US97/16451	WO 98/10732	–	PCT/US97/17158	WO 98/13195	–
PCT/US97/16511	WO 98/12635	–	PCT/US97/17160	WO 98/14777	–
PCT/US97/16531	WO 98/14111	–	PCT/US97/17188	WO 98/13116	–
PCT/US97/16537	WO 98/17981	–	PCT/US97/17194	WO 98/13088	–
PCT/US97/16559	WO 98/14927	–	PCT/US97/17209	WO 98/16282	–
PCT/US97/16589	WO 98/12205	–	PCT/US97/17235	WO 98/13222	–
PCT/US97/16664	WO 98/11841	–	PCT/US97/17250	WO 98/13557	–
PCT/US97/16700	WO 98/14048	–	PCT/US97/17279	WO 98/13825	–
PCT/US97/16727	WO 98/15042	–	PCT/US97/17282	WO 98/13007	–
PCT/US97/16737	WO 98/11847	–	PCT/US97/17313	WO 98/14275	–
PCT/US97/16800	WO 98/12268	–	PCT/US97/17323	WO 98/15070	–
PCT/US97/16834	WO 98/13151	–	PCT/US97/17362	WO 98/13380	–
PCT/US97/16845	WO 98/14935	–	PCT/US97/17377	WO 98/13796	–
PCT/US97/16871	WO 98/13908	–	PCT/US97/17442	WO 98/14754	–
PCT/US97/16877	WO 98/24179	–	PCT/US97/17444	WO 98/14924	–
PCT/US97/16878	WO 98/18261	–	PCT/US97/17468	WO 98/14838	–
PCT/US97/16894	WO 98/16966	–	PCT/US97/17481	WO 98/15108	–
PCT/US97/16898	WO 98/11980	–	PCT/US97/17491	WO 98/22968	–
PCT/US97/16934	WO 98/16408	–	PCT/US97/17510	WO 98/14467	–
PCT/US97/16960	WO 98/13664	–	PCT/US97/17517	WO 98/15059	–
PCT/US97/16972	WO 98/17345	–	PCT/US97/17544	WO 98/17708	–
PCT/US97/16973	WO 98/17546	–	PCT/US97/17549	WO 98/19501	–
PCT/US97/16989	WO 98/18725	–	PCT/US97/17564	WO 98/14237	–
PCT/US97/16990	WO 98/11814	–	PCT/US97/17566	WO 98/20644	–
PCT/US97/17003	WO 98/12530	–	PCT/US97/17612	WO 98/14970	–
PCT/US97/17004	WO 98/12616	–	PCT/US97/17613	WO 98/14139	–
PCT/US97/17011	WO 98/13571	–	PCT/US97/17645	WO 98/14290	–
PCT/US97/17042	WO 98/13941	–	PCT/US97/17651	WO 98/14128	–
PCT/US97/17046	WO 98/14003	–	PCT/US97/17653	WO 98/14936	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**	**International Application Numbers** **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**
PCT/US97/17661	WO 98/14886	–	PCT/US97/18055	WO 98/22418	–
PCT/US97/17682	WO 98/14641	–	PCT/US97/18056	WO 98/15795	–
PCT/US97/17696	WO 98/19013	–	PCT/US97/18062	WO 98/15811	–
PCT/US97/17699	WO 98/17702	–	PCT/US97/18104	WO 98/15293	–
PCT/US97/17702	WO 98/14485	–	PCT/US97/18112	WO 98/16199	–
PCT/US97/17706	WO 98/14901	–	PCT/US97/18118	WO 98/15857	–
PCT/US97/17725	WO 98/21678	–	PCT/US97/18129	WO 98/15198	–
PCT/US97/17731	WO 98/18016	–	PCT/US97/18132	WO 98/15473	–
PCT/US97/17733	WO 98/20185	–	PCT/US97/18139	WO 98/15621	–
PCT/US97/17742	WO 98/14570	–	PCT/US97/18141	WO 98/15920	–
PCT/US97/17744	WO 98/14571	–	PCT/US97/18143	WO 98/15645	–
PCT/US97/17745	WO 98/14612	–	PCT/US97/18145	WO 98/15179	–
PCT/US97/17749	WO 98/17777	–	PCT/US97/18162	WO 98/15812	–
PCT/US97/17751	WO 98/15862	–	PCT/US97/18167	WO 98/16069	–
PCT/US97/17752	WO 98/14179	–	PCT/US97/18182	WO 98/17494	–
PCT/US97/17765	WO 98/15396	–	PCT/US97/18194	WO 98/18006	–
PCT/US97/17780	WO 98/19000	–	PCT/US97/18200	WO 98/17474	–
PCT/US97/17798	WO 98/15413	–	PCT/US97/18202	WO 98/16627	–
PCT/US97/17808	WO 98/19356	–	PCT/US97/18217	WO 98/16150	–
PCT/US97/17819	WO 98/18910	–	PCT/US97/18222	WO 98/15570	–
PCT/US97/17828	WO 98/15275	–	PCT/US97/18228	WO 98/15194	–
PCT/US97/17855	WO 98/17758	–	PCT/US97/18230	WO 98/16571	–
PCT/US97/17878	WO 98/15810	–	PCT/US97/18238	WO 98/17603	–
PCT/US97/17891	WO 98/14572	–	PCT/US97/18243	WO 98/18527	–
PCT/US97/17909	WO 98/16492	–	PCT/US97/18247	WO 98/15994	–
PCT/US97/17915	WO 98/15894	–	PCT/US97/18248	WO 98/17045	–
PCT/US97/17919	WO 98/15218	–	PCT/US97/18259	WO 98/14579	–
PCT/US97/17927	WO 98/16174	–	PCT/US97/18265	WO 98/15380	–
PCT/US97/17979	WO 98/21641	–	PCT/US97/18280	WO 98/16503	–
PCT/US97/17996	WO 98/15228	–	PCT/US97/18288	WO 98/16164	–
PCT/US97/18000	WO 98/14514	–	PCT/US97/18293	WO 98/16646	–
PCT/US97/18013	WO 98/17301	–	PCT/US97/18296	WO 98/16821	–
PCT/US97/18023	WO 98/14402	–	PCT/US97/18304	WO 98/16720	–
PCT/US97/18048	WO 98/14534	–	PCT/US97/18323	WO 98/15563	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/US97/18332	WO 98/15816	–	PCT/US97/18584	WO 98/16903	–
PCT/US97/18336	WO 98/16046	–	PCT/US97/18586	WO 98/17513	–
PCT/US97/18351	WO 98/16068	–	PCT/US97/18592	WO 98/16373	–
PCT/US97/18366	WO 98/16450	–	PCT/US97/18600	WO 98/16151	–
PCT/US97/18386	WO 98/20170	–	PCT/US97/18602	WO 98/16729	–
PCT/US97/18387	WO 98/16184	–	PCT/US97/18606	WO 98/17252	–
PCT/US97/18388	WO 98/16444	–	PCT/US97/18613	WO 98/16907	–
PCT/US97/18412	WO 98/16256	–	PCT/US97/18615	WO 98/16142	–
PCT/US97/18415	WO 98/16160	–	PCT/US97/18616	WO 98/17369	–
PCT/US97/18430	WO 98/16236	–	PCT/US97/18618	WO 98/17871	–
PCT/US97/18433	WO 98/16671	–	PCT/US97/18623	WO 98/16968	–
PCT/US97/18435	WO 98/19164	–	PCT/US97/18626	WO 98/23980	–
PCT/US97/18437	WO 98/16771	–	PCT/US97/18628	WO 98/16801	–
PCT/US97/18447	WO 98/16779	–	PCT/US97/18630	WO 98/16192	–
PCT/US97/18456	WO 98/17467	–	PCT/US97/18633	WO 98/18249	–
PCT/US97/18465	WO 98/16211	–	PCT/US97/18636	WO 98/17157	–
PCT/US97/18489	WO 98/18922	–	PCT/US97/18637	WO 98/16226	–
PCT/US97/18497	WO 98/17224	–	PCT/US97/18646	WO 98/16115	–
PCT/US97/18500	WO 98/18507	–	PCT/US97/18651	WO 98/16532	–
PCT/US97/18504	WO 98/16757	–	PCT/US97/18652	WO 98/16154	–
PCT/US97/18515	WO 98/19738	–	PCT/US97/18662	WO 98/17396	–
PCT/US97/18518	WO 98/16165	–	PCT/US97/18665	WO 98/17821	–
PCT/US97/18532	WO 98/16278	–	PCT/US97/18675	WO 98/16893	–
PCT/US97/18535	WO 98/17071	–	PCT/US97/18678	WO 98/15740	–
PCT/US97/18536	WO 98/17770	–	PCT/US97/18699	WO 98/17307	–
PCT/US97/18537	WO 98/15399	–	PCT/US97/18711	WO 98/17619	–
PCT/US97/18542	WO 98/16939	–	PCT/US97/18712	WO 98/16890	–
PCT/US97/18546	WO 98/16200	–	PCT/US97/18716	WO 98/17299	–
PCT/US97/18554	WO 98/17044	–	PCT/US97/18718	WO 98/16238	–
PCT/US97/18557	WO 98/16134	–	PCT/US97/18720	WO 98/18572	–
PCT/US97/18562	WO 98/15454	–	PCT/US97/18724	WO 98/17725	–
PCT/US97/18567	WO 98/17505	–	PCT/US97/18732	WO 98/20290	–
PCT/US97/18580	WO 98/16289	–	PCT/US97/18733	WO 98/17487	–
PCT/US97/18582	WO 98/16265	–	PCT/US97/18743	WO 98/15273	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/US97/18753	WO 98/16168	–	PCT/US97/19047	WO 98/18145	–
PCT/US97/18754	WO 98/17227	–	PCT/US97/19054	WO 98/18159	–
PCT/US97/18764	WO 98/16401	–	PCT/US97/19055	WO 98/17316	–
PCT/US97/18765	WO 98/16709	–	PCT/US97/19058	WO 98/17171	–
PCT/US97/18767	WO 98/16186	–	PCT/US97/19063	WO 98/18815	–
PCT/US97/18769	WO 98/16626	–	PCT/US97/19067	WO 98/17842	–
PCT/US97/18802	WO 98/15171	–	PCT/US97/19071	WO 98/16515	–
PCT/US97/18816	WO 98/16783	–	PCT/US97/19092	WO 98/20513	–
PCT/US97/18818	WO 98/18412	–	PCT/US97/19108	WO 98/17209	–
PCT/US97/18821	WO 98/17243	–	PCT/US97/19127	WO 98/17366	–
PCT/US97/18825	WO 98/15453	–	PCT/US97/19130	WO 98/16897	–
PCT/US97/18831	WO 98/17524	–	PCT/US97/19136	WO 98/16617	–
PCT/US97/18850	WO 98/19320	–	PCT/US97/19139	WO 98/16734	–
PCT/US97/18853	WO 98/17242	–	PCT/US97/19143	WO 98/16257	–
PCT/US97/18856	WO 98/17169	–	PCT/US97/19144	WO 98/17843	–
PCT/US97/18890	WO 98/16717	–	PCT/US97/19150	WO 98/19131	–
PCT/US97/18900	WO 98/23183	–	PCT/US97/19152	WO 98/23411	–
PCT/US97/18901	WO 98/16205	–	PCT/US97/19182	WO 98/17737	–
PCT/US97/18922	WO 98/18110	–	PCT/US97/19208	WO 98/18734	–
PCT/US97/18925	WO 98/18015	–	PCT/US97/19210	WO 98/17275	–
PCT/US97/18931	WO 98/17136	–	PCT/US97/19219	WO 98/18939	–
PCT/US97/18941	WO 98/18130	–	PCT/US97/19228	WO 98/22471	–
PCT/US97/18944	WO 98/18480	–	PCT/US97/19230	WO 98/18473	–
PCT/US97/18968	WO 98/17679	–	PCT/US97/19233	WO 98/23451	–
PCT/US97/18976	WO 98/16742	–	PCT/US97/19236	WO 98/18523	–
PCT/US97/18980	WO 98/21211	–	PCT/US97/19240	WO 98/18531	–
PCT/US97/18999	WO 98/19237	–	PCT/US97/19246	WO 98/19229	–
PCT/US97/19005	WO 98/22768	–	PCT/US97/19247	WO 98/19183	–
PCT/US97/19009	WO 98/17637	–	PCT/US97/19265	WO 98/18546	–
PCT/US97/19010	WO 98/16919	–	PCT/US97/19277	WO 98/19059	–
PCT/US97/19023	WO 98/17826	–	PCT/US97/19278	WO 98/18978	–
PCT/US97/19039	WO 98/17483	–	PCT/US97/19284	WO 98/19088	–
PCT/US97/19041	WO 98/23761	–	PCT/US97/19287	WO 98/19877	–
PCT/US97/19044	WO 98/16554	–	PCT/US97/19291	WO 98/19294	–

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INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international	International Application Numbers Numéros des demandes internationales	International Publication Numbers Numéros de publication internationale	Designated States not Elected in the Demand États désignés non élus dans la demande d'examen préliminaire international
PCT/US97/19292	WO 98/19408	–	PCT/US97/19597	WO 98/18914	–
PCT/US97/19317	WO 98/17205	–	PCT/US97/19607	WO 98/18925	–
PCT/US97/19322	WO 98/17707	–	PCT/US97/19611	WO 98/19721	–
PCT/US97/19330	WO 98/17110	–	PCT/US97/19615	WO 98/19599	–
PCT/US97/19340	WO 98/17609	–	PCT/US97/19619	WO 98/18312	–
PCT/US97/19343	WO 98/17253	–	PCT/US97/19625	WO 98/19879	–
PCT/US97/19348	WO 98/18460	–	PCT/US97/19626	WO 98/20422	–
PCT/US97/19349	WO 98/18461	–	PCT/US97/19674	WO 98/17254	–
PCT/US97/19352	WO 98/17430	–	PCT/US97/19714	WO 98/20810	–
PCT/US97/19361	WO 98/17111	–	PCT/US97/19734	WO 98/20668	–
PCT/US97/19390	WO 98/17541	–	PCT/US97/19750	WO 98/19268	–
PCT/US97/19398	WO 98/19210	–	PCT/US97/19773	WO 98/18376	–
PCT/US97/19417	WO 98/17337	–	PCT/US97/19774	WO 98/19262	–
PCT/US97/19425	WO 98/17112	–	PCT/US97/19788	WO 98/20129	–
PCT/US97/19432	WO 98/17580	–	PCT/US97/19796	WO 98/21087	–
PCT/US97/19433	WO 98/17618	–	PCT/US97/19799	WO 98/18311	–
PCT/US97/19439	WO 98/19196	–	PCT/US97/19800	WO 98/20720	–
PCT/US97/19446	WO 98/18290	–	PCT/US97/19804	WO 98/18932	–
PCT/US97/19457	WO 98/17828	–	PCT/US97/19825	WO 98/20709	–
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PCT/US97/19470	WO 98/16849	–	PCT/US97/19868	WO 98/21902	–
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PCT/US97/19476	WO 98/17626	–	PCT/US97/19898	WO 98/20312	–
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PCT/US97/19531	WO 98/18314	–	PCT/US97/19948	WO 98/19618	–
PCT/US97/19538	WO 98/19272	–	PCT/US97/19950	WO 98/21492	–
PCT/US97/19540	WO 98/17108	–	PCT/US97/19994	WO 98/23645	–
PCT/US97/19543	WO 98/18077	–	PCT/US97/20019	WO 98/19977	–
PCT/US97/19554	WO 98/17740	–	PCT/US97/20050	WO 98/20590	–
PCT/US97/19575	WO 98/18323	–	PCT/US97/20052	WO 98/20060	–
PCT/US97/19585	WO 98/19700	–	PCT/US97/20053	WO 98/20348	–
PCT/US97/19589	WO 98/17113	–	PCT/US97/20062	WO 98/19751	–
PCT/US97/19590	WO 98/17687	–	PCT/US97/20067	WO 98/19595	–
PCT/US97/19595	WO 98/19682	–	PCT/US97/20069	WO 98/20036	–

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(Suite sur la page suivante)

INTERNATIONAL APPLICATIONS FOR WHICH A DEMAND HAS BEEN FILED PRIOR TO THE EXPIRATION OF THE 19TH MONTH FROM THE PRIORITY DATE (Continued)

DEMANDES INTERNATIONALES POUR LESQUELLES UNE DEMANDE D'EXAMEN PRÉLIMINAIRE INTERNATIONAL A ÉTÉ PRÉSENTÉE AVANT L'EXPIRATION D'UNE PÉRIODE DE 19 MOIS À COMPTER DE LA DATE DE PRIORITÉ (Suite)

International Application Numbers **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**	**International Application Numbers** **Numéros des demandes internationales**	**International Publication Numbers** **Numéros de publication internationale**	**Designated States not Elected in the Demand** **États désignés non élus dans la demande d'examen préliminaire international**
PCT/US97/20216	WO 98/19565	–	PCT/US97/20603	WO 98/21348	–
PCT/US97/20235	WO 98/21269	–	PCT/US97/20690	WO 98/20857	–
PCT/US97/20243	WO 98/20704	–	PCT/US97/20702	WO 98/20131	–
PCT/US97/20255	WO 98/20197	–	PCT/US97/20748	WO 98/21376	–
PCT/US97/20277	WO 98/23079	–	PCT/US97/20773	WO 98/23220	–
PCT/US97/20307	WO 98/20445	–	PCT/US97/20838	WO 98/23492	–
PCT/US97/20331	WO 98/21170	–	PCT/US97/20839	WO 98/21609	–
PCT/US97/20360	WO 98/23255	–	PCT/US97/20846	WO 98/19635	–
PCT/US97/20363	WO 98/23789	–	PCT/US97/20847	WO 98/19636	–
PCT/US97/20368	WO 98/21572	–	PCT/US97/20869	WO 98/20770	–
PCT/US97/20369	WO 98/21108	–	PCT/US97/20922	WO 98/20321	–
PCT/US97/20388	WO 98/19701	–	PCT/US97/20923	WO 98/19681	–
PCT/US97/20438	WO 98/20347	–	PCT/US97/20931	WO 98/22396	–
PCT/US97/20463	WO 98/22932	–	PCT/US97/21063	WO 98/21235	–
PCT/US97/20508	WO 98/20828	–	PCT/US97/21082	WO 98/22837	–
PCT/US97/20538	WO 98/20439	–	PCT/US97/21196	WO 98/23355	–
PCT/US97/20543	WO 98/23681	–	PCT/US97/21203	WO 98/21610	–
PCT/US97/20559	WO 98/20925	–	PCT/US97/21248	WO 98/21343	–
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PCT/US97/20588	WO 98/21732	–	PCT/US97/21422	WO 98/24041	–
PCT/US97/20592	WO 98/20649	–	PCT/US97/21607	WO 98/24242	–
			PCT/US97/21615	WO 98/23838	–
			PCT/US97/21704	WO 98/23217	–
			PCT/US97/21865	WO 98/23782	–
			PCT/US97/22503	WO 98/23643	–
			PCT/US97/22511	WO 98/23448	–

EXHIBIT 1058A

DISSERTATION

Micro accelerometer design with digital feedback control / by Mark Alan Lemkin.

Lemkin, Mark Alan.

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Title	Micro accelerometer design with digital feedback control / by Mark Alan Lemkin.
Creator / Contributor	Lemkin, Mark Alan. ›
Publisher	1997.
Creation date	1997
Format	vii, 114 leaves : illustrations ; 28 cm
Notes	Includes bibliographical references (leaves 109-114).
Dissertation	Thesis (Ph. D. in Engineering-Mechanical Engineering)--University of California, Berkeley, Dec. 1997.
Subject	Dissertations, Academic UCB Engineering 1991-2000.
Genre	dissertations Academic theses Thèses et écrits académiques
Related titles	Available in other form: Online version: Lemkin, Mark Alan. Micro accelerometer design with digital feedback control. 1997 ›
Source	Library Catalog

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338     ##$avolume $bnc $2rdacarrier
502     ##$aThesis (Ph. D. in Engineering-Mechanical Engineering)--University of California, Berkeley, Dec. 1997.
504     ##$aIncludes bibliographical references (leaves 109-114).
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Electronic Book Pilot Project - (UCB only)

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Try new features in our Experimental version of Pathfinder. You can query all the Melvyl article databases with one search. Also, several new databases from SilverPlatter are available through the Experimental Pathfinder interface.

UCB Logon Use the UCB Logon link at the left to logon to Pathfinder for additional services. At the moment the only services available are the Baker Document Delivery Service and remote access to restricted databases such as MAGS and Current Contents. We hope to make other services, like paging from storage, available soon. Please send us your comments and suggestions! Just click on the **Comments** button in the toolbar at the top of any page.

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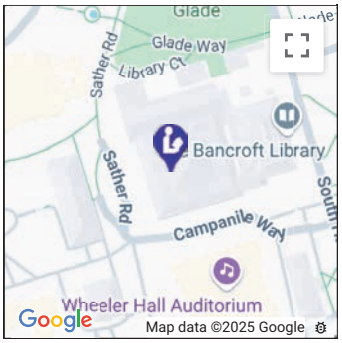
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Statistics Academic		
Enrollment	43,584	**FTE Students**
Collection size	16,217,948	**volumes**
Annual Circulation	707,825	**transactions**



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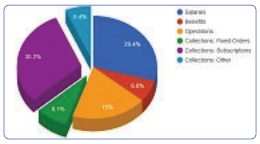


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Previous Automation System	Locally developed	1972
Discovery Service (w/index)	Ex Libris CDI	2019
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Discovery Interface	Primo	2019
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Author(s): Lemkin, Mark Alan.

Year: 1997

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Dissertation: Thesis (Ph. D. in Engineering-Mechanical Engineering)--University of California, Berkeley, Dec. 1997.

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EXHIBIT 1058D

ISSN 0277-0288

Library Systems Newsletter

Published by Library Technology Reports • American Library Association
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Library Systems Newsletter [November 1991]



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Abstract

In this work, design of capacitive accelerometers with CMOS electronics is investigated. The goal of this investigation is to form accurate behavioral models at three different levels of abstraction: system, electrical, and mechanical. Analysis of these models permits a deeper understanding of both accelerometer design and design trade-offs. The results of this work are used to obtain an accurate prediction of accelerometer performance.

At the system level, simultaneous force-balancing and analog-to-digital conversion of the analog input acceleration to digital output is achieved using a sigma-delta force-feedback loop. Analysis of the feedback loop shows that the system is unstable without compensation. Compensation of the feedback loop is accomplished with a forward path, discrete-time lead filter. Modeling and simulations are used to determine optimal compensator characteristics and system robustness.

Design of CMOS-compatible interface electronics is also investigated. Time-multiplexing of the sigma-delta feedback loop enables errors introduced by the electronic interface to be measured and canceled. A method of interfacing the sense-element to a fully-differential electrical interface is described. To obtain accurate predictions of resolution, a detailed noise analysis is presented. Fabricated devices invariable exhibit an acceleration offset due to mismatches from the manufacturing process. A technique for trimming this offset after packaging is demonstrated.

Mechanical design of the sense-element is found to play a fundamental role in the determination of both dynamic range and noise floor. Understanding of factors determining mechanical sensitivity, noise, and robustness is obtained through detailed analyses.

Efficacy of both the design techniques and the analytical models developed through this research has been experimentally verified. The experimental test-bed used for verification is a monolithic three-axis

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surface micromachined accelerometer. The 0.2 micro-gram proof-mass is formed from a 2.3 micron-thick layer of polysilicon. A measured dynamic range of 84 dB, 81 dB and 70 dB is achieved in the x-, y-, and z-axes respectively. While the 4mm x 4mm chip operates from a 5 Volt power supply, the proposed design techniques are applicable to low voltage technologies. Comparisons of calculated, simulated, and measured parameters show excellent agreement between modeled and observed behaviors.

Less ^

Details

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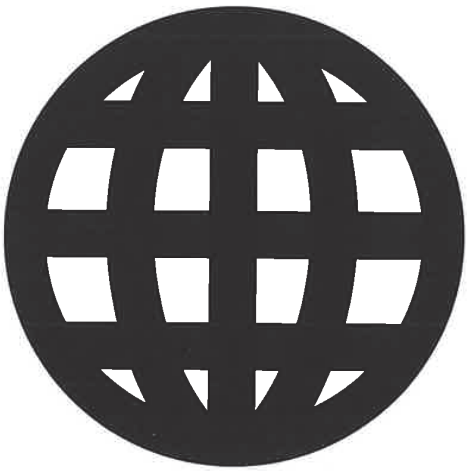
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- Reading
- Religious
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- Sociology of
- Special
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- Linguistics
- Modern

Literature
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This thesis propose an universal representation with four essential criteria: (1) ability to reproduce the static nature of the signature: the image of the signature; (2) ability to represent the dynamic aspects of the signature; (3) provide description of the signature with parameters; (4) accept different transformations: translation, rotation, and homomorphy in relation to time and space.

To meet this objective, we have: (1) transposed a model of rapid human to generate complex lines that complex a signature; (2) solved the problem of extraction of the parameters according to the model. For the extraction of parameters, a non-linear regression was used at two level: (1) to analyze the image of the signature for extraction of virtual targets; (2) to analyze the dynamic aspect of the signature.

Following the proposed signature's representation, this thesis demonstrates the validation of 220 signatures encompassing many types: arabic, european, american and chinese. The validation was done with an automatic verification system. The results confirmed the validity of the proposed representation.

The representation of signatures allow to propose a hypothesis regarding the creation of learned complex movements within the framework of the signing motion. The thesis also give an approach to solve the extraction problem of parameter from the model with the utilization of visual targets like the starting point for the construction of the signature.

This proposed representation should favor the creation of a signature verification system due to its parametric nature. Moreover, the parametric approach allows the compression of data, that would be beneficial in the context of bank transactions, which require the storage million of signatures. Finally the representation model allows the opening of possibilities for understanding complex movements.

Interference suppression for DS/CDMA systems in non-Gaussian impulsive channels. Lee, Seoyoung, Ph.D. *Iowa State University,* 1998. 119pp. Major Professor: Julie Dickerson

Order Number DA9826551

Multiple-access interference (MAI) suppression techniques in DS/CDMA systems usually assume additive Gaussian noise. Minimum mean squared error (MMSE) detectors are near-far resistant in additive Gaussian noise channels. But the additive channel noise in many communication channels is often non-Gaussian and impulsive. Signal detection in non-Gaussian impulsive noise is traditionally focused on single-user channels. Symmetric alpha-stable ($S\alpha S$) probability density functions can accurately model large classes of impulsive noise. The MMSE performance criterion cannot be used for $S\alpha S$ processes with $0 < \alpha < 2$ since they have infinite variance. This dissertation considers the problems of MAI suppression for DS/CDMA systems in the presence of additive non-Gaussian impulsive channel noise modeled as a $S\alpha S$ process with $1 < \alpha < 2$. These MAI suppression techniques help combat the near-far problem. First, the minimum dispersion (MD) criterion is introduced to suppress MAI. Linear MD detection can be viewed as expansion of the concept of the MMSE detection for Gaussian multiple-access channels to $S\alpha S$ non-Gaussian impulsive multiple-access channels. The linear MD detector is implemented adaptively using least mean p-norm (LMP) algorithm. The performance of the linear MD detector is analyzed in the context of a $S\alpha S$ process. Simulation results indicate that the adaptive MD detector shows good near-far resistance. Next, this dissertation presents a MRI suppression method using the least L_p-norm criterion. The iteratively reweighted least squares (IRLS) algorithm recursively approximates the least L_p-norm solution from weighted normal equations. Simulation results show that the proposed detector provides remarkable performance improvements over the adaptive MD detector in a wide range of near-far situations. The proposed detector has much better near-far resistance than the adaptive MD detector. Finally, fuzzy hybrid detector combines the adaptive MD detector and the hard-limiting matched filter (HLMF) detector. The HLMF detector performs well when the additive impulsive noise significantly dominates over MAI. Simulation results indicate significant performance improvements over the adaptive MD detector alone in impulsive noise-limited environments. When MAI dominates, the fuzzy hybrid detector nearly has the same performance as the adaptive MD detector.

Approximate model checking. Lee, Woohyuk, Ph.D. *University of Colorado at Boulder,* 1998. 103pp. Director: Fabio Somenzi

Order Number DA9827736

In the past few years, formal verification has gained attention from the digital circuit design community. However, formal verification methods are still not considered as the mainstream verification methodology in practice. We believe this is because the algorithms of the formal methods, in general, require heavy computational power which make them infeasible to be applied in the daily verification tasks.

This thesis focuses on making formal verification feasible for the real life designs. We use ∀CTL and CTL model checking to formally verify the system. The introduction of the symbolic approach (BDD) has significantly improved model checking; however the method alone still cannot handle production level circuits. We rely on conservative verification algorithm to reduce the computational complexity of the given problem. Our conservative verification algorithm contains two sub-algorithms: conservative positive and conservative negative verification algorithm. Conservative positive (negative) algorithm is responsible for proving true positive (negative) of a given formula.

We introduce two distinct approximation strategies for conservative verification: tearing abstraction and BDD abstraction. The tearing based abstraction technique abstracts the system from the circuit level. The BDD abstraction technique directly applies abstraction to the structure of BDDs. The two methods are combined into a single verification framework to improve the quality of approximations.

The verification process starts from a coarse approximation and refines it until a reliable result is produced. The refinement strategy is based on the theory of the lattice of approximations. The theory of the lattice of approximations provides a systematic way to generate successive refinements. The lattice contains two sub-lattices, one for the over-approximations and the other for the under-approximations. The exact system is located in the middle and the lattice of over-approximations above it and the lattice of underapproximations beneath the exact system.

The study indicates that the formal method is applicable to the industrial strength circuits. We used a state-of-the-art 2x2 scalable ATM switching fabric circuit to test the new algorithms.

Empirical detection for spread spectrum and code division multiple access (CDMA) communications. Lee, Yuan Kang, Ph.D. *Rice University,* 1998. 147pp. Adviser: Don H. Johnson

Order Number DA9827413

In this thesis, the method of "classification with empirically observed statistics"—also known as empirical classification, empirical detection, universal classification, and type-based detection—is configured and applied to the despreading/detection receiver operation of a spread-spectrum (SS), code division multiple access (CDMA) communications system. In static and Rayleigh-fading environments, the empirical detector is capable of adapting to unknown noise environments in a superior manner than the linear matched-filter despreader/detector, and done with reasonable amounts of training. Compared to the optimum detector, when known, the empirical detector always approaches optimal performance, again, with reasonable amounts of training. In an interference-limited channel, we show that the single-user likelihood-ratio detector, which is the optimum single-user detector, can greatly outperform the matched filter in certain imperfect power-control situations. The near optimality of the empirical detector implies that it, too, will outperform the matched filter in these situations. Although the empirical detector has the added cost of requiring chip-based phase synchronization, its consistent and superior performance in all environments strongly suggests its application in lieu of the linear detector for SS/CDMA systems employing long, pseudo-random spreading. In order to apply empirical classification to digital communications, we derive the empirical forced-decision detector and show that it is asymptotically optimal over a large class of empirical classifiers.

Micro accelerometer design with digital feedback control. Lemkin, Mark Alan, Ph.D. *University of California, Berkeley,* 1997. 114pp. Chair: David M. Auslander

Order Number DA9827011

In this work, design of capacitive accelerometers with CMOS electronics is investigated. The goal of this investigation is to form accurate behavioral models at three different levels of abstraction: system,

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electrical, and mechanical. Analysis of these models permits a deeper understanding of both accelerometer design and design trade-offs. The results of this work are used to obtain an accurate prediction of accelerometer performance.

At the system level, simultaneous force-balancing and analog-to-digital conversion of the analog input acceleration to digital output is achieved using a sigma-delta force-feedback loop. Analysis of the feedback loop shows that the system is unstable without compensation. Compensation of the feedback loop is accomplished with a forward path, discrete-time lead filter. Modeling and simulations are used to determine optimal compensator characteristics and system robustness.

Design of CMOS-compatible interface electronics is also investigated. Time-multiplexing of the sigma-delta feedback loop enables errors introduced by the electronic interface to be measured and canceled. A method of interfacing the sense-element to a fully-differential electrical interface is described. To obtain accurate predictions of resolution, a detailed noise analysis is presented. Fabricated devices invariable exhibit an acceleration offset due to mismatches from the manufacturing process. A technique for trimming this offset after packaging is demonstrated.

Mechanical design of the sense-element is found to play a fundamental role in the determination of both dynamic range and noise floor. Understanding of factors determining mechanical sensitivity, noise, and robustness is obtained through detailed analyses.

Efficacy of both the design techniques and the analytical models developed through this research has been experimentally verified. The experimental test-bed used for verification is a monolithic three-axis surface micromachined accelerometer. The 0.2 micro-gram proof-mass is formed from a 2.3 micron-thick layer of polysilicon. A measured dynamic range of 84 dB, 81 dB and 70 dB is achieved in the x-, y-, and z-axes respectively. While the 4mm x 4mm chip operates from a 5 Volt power supply, the proposed design techniques are applicable to low voltage technologies. Comparisons of calculated, simulated, and measured parameters show excellent agreement between modeled and observed behaviors.

Modelling and analysis of system state estimation with communication constraints. Li, Xia, Ph.D. *Chinese University of Hong Kong (People's Republic of China),* 1997. 134pp. Adviser: Wong Wing Shing **Order Number DA9826936**

Estimation of the internal states of a stochastic dynamic system (using the system inputs and outputs as a basis for that estimation) is a topic with important applications. In this thesis, we deal with a constrained state estimation problem. The primary motivation of this work is provided by problems arising in the estimation of the state variables at a remote location using discrete time observations via a digital communication channel with a low data rate. This may be caused by the physical constraints, or by the architectural constraints, for example, when a large number of distributed plants is served by a common decision maker. The goal of this thesis is to develop a theoretical framework to investigate the communication-constrained estimation problem, and to gain more insight into the issue of the interaction of coding and estimation, as well as to study the impact of delay due to finite communication capacity constraints.

Our approach has been to formulate the problem as a tradeoff between the channel rate R_c and the rate of change of system dynamics. Unlike the *i.i.d.* models typically assumed in rate distortion theory, the model considered here is common in system and control problems, except that the observations have to be encoded and suffer transmission delays. The main tool used is a combined coding estimation scheme which is recursive in nature. We introduce an important index, $M\Delta^2$, which is critical in studying the rate of convergence of various coding estimation schemes. In estimating a random state variable, the asymptotic rate of convergence is shown to be 1/4 for various coding estimation schemes. For estimating a random state variable under the influence of a deterministic dynamics, a sufficient and necessary condition on the channel rate is obtained for the 1-bit mean (or midpoint) coder-estimator sequences to converge in quadratic mean as well as in aggregated quadratic mean. A hybrid coding estimation scheme is proposed, which achieves nearly the performance of the mean coding estimation scheme with the efficiency of the midpoint one, the time to swap between these two schemes is determined by the values of $M_t\Delta_t^2$ at that time.

For a system contaminated with observation noise, the relation between the necessary channel rate, the rate of change of system dynamics, and the asymptotic mean square estimation error bound on the resulting 1-bit mean coder-estimator sequence is obtained analytically. Furthermore, preliminary study of the state estimation problem for systems with process noise and transmission errors is also performed.

Finally, we apply the results in the communication-constrained estimation theory to the power control problem in a mobile cellular system. Numerical results show its effectiveness.

It is hoped that the results obtained in this thesis may contribute towards a better understanding of the issue of how information processing and the underlying system dynamics interact in a tightly coupled manner as well as the practical design issues.

Robust speech coding using microphone arrays. Li, Zhao, Ph.D. *The University of Nebraska - Lincoln,* 1998. 186pp. Supervisors: Michael W. Hoffman; Khalid Sayood **Order Number DA9826091**

To achieve robustness and efficiency for voice communication in noise, the noise suppression and bandwidth compression processes are combined to form a joint process using input from an array of microphones. An adaptive beamforming technique with a set of robust linear constraints and a single quadratic inequality constraint is used to preserve desired signal and to cancel directional plus ambient noise in a small room environment. This robustly constrained array processor is found to be effective in limiting signal cancelation over a wide range of input SNRs (−10 dB to +10 dB). The resulting intelligibility gains (8–10 dB) provide significant improvement to subsequent CELP coding. In addition, the desired speech activity is detected by estimating Target-to-Jammer Ratios (TJR) using subband correlations between different microphone inputs or using signals within the Generalized Sidelobe Canceler directly. These two novel techniques of speech activity detection for coding are studied thoroughly in this dissertation. Each is subsequently incorporated with the adaptive array and a 4.8 kbps CELP coder to form a Variable Bit Kate (VBR) coder with noise canceling and Spatial Voice Activity Detection (SVAD) capabilities. This joint noise suppression and bandwidth compression system demonstrates large improvements in desired speech quality after coding, accurate desired speech activity detection in various types of interference, and a reduction in the information bits required to code the speech.

An unsupervised neural network fault discriminating system implementation for on-line condition monitoring and diagnostics of induction machines. Lin, Brian K., Ph.D. *Georgia Institute of Technology,* 1998. 112pp. Director: Jay H. Schlag **Order Number DA9827350**

A new method for on-line classification of induction machine faults was proposed. The proposed system included an unsupervised neural network and two expert systems. This system was designed to detect and categorize incipient machine failures autonomously. Stator current (single phase) were collected from machines with inflicted damages and were analyzed by the system. The first of the two expert systems extracted stator current features thus allowing spectral information compression while the second classified fault types when a failure condition had been detected by the neural network. The results have indicated that this combination of neural and knowledge systems an effective method of classifying incipient failures in a line-operated induction machine.

A test planning system for functional validation of VHDL DSP models. Lin, Morris Mengwei, Ph.D. *Virginia Polytechnic Institute and State University,* 1998. 177pp. Chair: James R. Armstrong **Order Number DA9822047**

Validating DSP circuits modeled in VHDL involves generating test data, creating VHDL test benches, and simulating the test benches including models under test (MUTs). This is a laborious and time-consuming process. Therefore, it is desirable to develop a high level approach to automating and planning these tasks.

This dissertation presents a high level test planning system for functional validation of VHDL DSP models. The system requirements parameterized from the specifications constitute the input space and serve as generics of test benches. Library-based test benches are developed

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A Monolithic Surface Micromachined Accelerometer with Digital Output

Crist Lu, Mark Lemkin, and Bernhard E. Boser, *Member, IEEE*

***Abstract*— A surface micromachined accelerometer with on-chip electronics realized in a 3 μm BiCMOS technology is described. The sensing element consists of a thin film of polysilicon that is deposited after fabrication of the electronic circuitry. Acceleration is measured by capacitively sensing sub-angstrom displacements of a mechanical proof-mass weighing 0.5 μgrams. The sensor uses force-feedback and achieves a resolution of 1.6 mg/$\sqrt{\text{Hz}}$ (1 g = 9.8 m/s^2). The limitations arising from the small size and mass of the sensing element and means for improvement are discussed. The small active die area of less than 3 mm^2 including the sensor along with the possibility to combine several different sensors on a single chip make this approach particularly attractive for applications demanding very small form factors.**

I. Introduction

INTEGRATED CIRCUITS play an important role in the process of gathering and processing "real world" information. In many cases, however, the actual sensing element is not part of the integrated circuit but fabricated in a different technology using substantially different tools and materials. As a result, the cost reductions and performance enhancements of IC solutions have not been fully realized.

Over the past decade, surface micromachining has become established as a technology for fabricating micromechanical structures from deposited thin films of polysilicon [1], aluminum [2], silicon nitride [3], [4], and other materials. Monolithic integration of surface microstructures with electronic circuitry is relatively straightforward and economically attractive with the microstructure typically occupying only a small fraction of the die area. By bringing the sense element onto the integrated circuit, surface micromachining leverages the experience and sophisticated processes of IC manufacturing and brings about all the customary advantages of integrated solutions: batch fabrication, high yield, small size, low power, and low cost. Elimination of a separate sense element miniaturizes the package and also results in improved reliability. For example, commercial surface micromachined accelerometers are rated for shocks in excess of 1000 g (1 g = 9.8 m/s^2) [5], [6], a level of robustness that is difficult to achieve with larger macroscale devices.

Several combined sensors and circuits technologies have been described in the literature [7], [8]. Applications include inertial sensors for acceleration and angular rate, as well as nonsensing functions such as low-drift clocks and high-Q, low-power electro-mechanical filters [9]. In addition to traditional sensor markets such as the automotive industry where this technology is competing with established approaches [10], an even bigger impact can be expected from future applications that take full advantage of the small size and versatility of surface micromachining. Motion sensors for head-mounted displays, for example, depend on very low-power, weight, and size sensors to track head movement in several directions. All these requirements can be met with a surface machined solution by combining several different sensing elements and all interface electronics on a single chip measuring only a few millimeters on a side.

In this paper, a surface micromachined acceleration sensor with on-chip electronics is described. The circuit is fabricated using Analog Device's BiMOS2e process, a 3 μm BiCMOS technology with an added layer of polysilicon used for building the mechanical sensing elements. Section II compares different choices for the sensing element and explores trade-offs between sensitivity and robustness of the devices. Potential performance limitations arising from the small size and extremely low mass, on the order of micro-grams, of typical polysilicon surface micromachined sensing elements are addressed as well.

The sense electronics used to detect subangstrom displacements of the sensing element due to acceleration inputs is described in Section III. The factors limiting the achievable resolution are evaluated and options for improvement analyzed. Feedback is explored in Section IV as a means to improve overall sensor performance. An experimental monolithic surface micromachined accelerometer and its measured performance are reported in Section V.

II. Sensing Element

For the technology used in this project [7], [11], mechanical elements consist of a 2 μm thick sheet of doped polysilicon suspended 1.6 μm above the substrate. The minimum width of beams is 2 μm, and the gap between adjacent features must be at least 1 μm. An additional mask specifies where structures are anchored to the substrate.

Despite the limitation to planar structures, a large variety of different sensors can be realized in this technology. Fig. 1 shows a conceptual diagram of two acceleration sensors with sensitivity to linear inputs perpendicular (z-axis) and parallel (x- or y-axis) to the chip surface. Both consist of a proof-mass anchored to the substrate with springs fabricated out of a single

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C. Lu was with the EECS Department, University of California at Berkeley, Berkeley, CA 94720 USA. He is now with Silicon Systems, Tustin, CA USA.

M. Lemkin is with the Mechanical Engineering Department, University of California at Berkeley, Berkeley CA 94720 USA.

B. Boser is with the EECS Department, University of California at Berkeley, Berkeley, CA 94720 USA.

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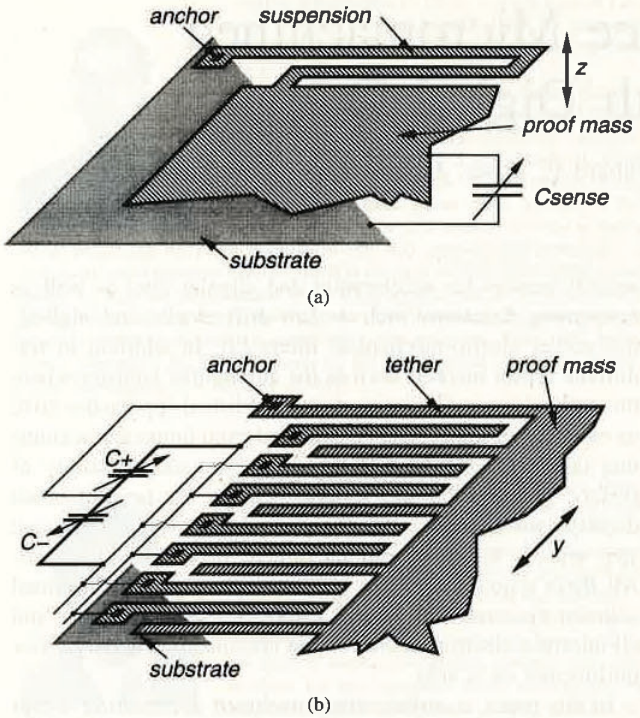


Fig. 1. Acceleration sensors with sensitivity to inputs (a) perpendicular and (b) parallel to the chip surface.

sheet of polysilicon. Acceleration of the sensor results in a displacement of the proof-mass with respect to the substrate that is sensed capacitively.

Both arrangements have their respective merits. The y-axis sensor uses a comb of stationary and movable electrodes for a fully differential readout. In the case of the z-axis sensor, the sense capacitor is formed by the substrate and the proof-mass itself. The inherent asymmetry of this interface leads to an offset and nonlinearity that must be compensated for in the electronic interface. Moreover, the sense voltage applied across the capacitor results in a pull-down force acting on the proof-mass that must be compensated by an equal pull-up force to prevent the sensor from collapsing onto the substrate.

The typically two to four times larger sense capacitance of z-axis structures in a given area is an advantage of this device. Even more importantly, the sensitivity to motion of the proof-mass and hence acceleration inputs is larger for devices that use a parallel plate capacitor for position sensing. This is because in the case of the sense combs used in x- or y-axis elements a substantial fraction of the sense capacitance is due to fringing fields and does not change appreciably due to small displacements. In the case of parallel plate capacitors, on the other hand, almost the entire parallel plate capacitor of the z-axis structure is sensitive to vertical motion of the proof mass. The increased sense capacitance and its higher sensitivity to displacement reduce the noise from the electronic position sense interface and result in a better resolution of the accelerometer provided that the problems arising from the asymmetry of the capacitive interface can be overcome.

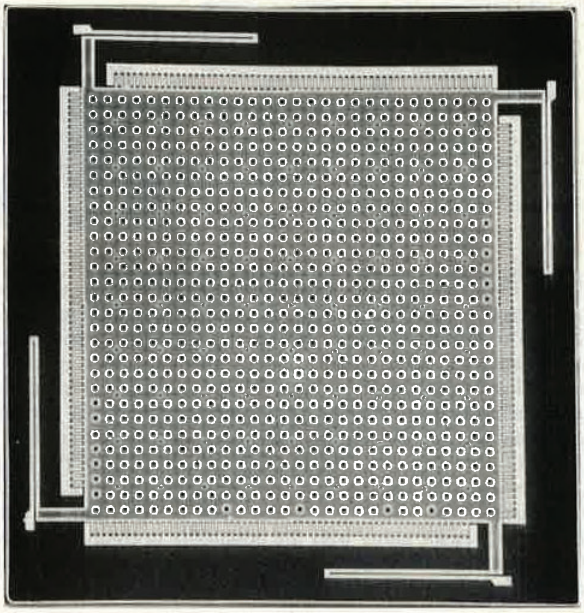


Fig. 2. Top-view of acceleration sensor.

A z-axis structure is used in this paper. In addition to the higher sense capacitance of this type of sensor, this choice is motivated by the need for a z-axis device in applications that demand acceleration measurement in several directions. Sensors with sensitivity parallel to the chip surface have already been demonstrated in surface micromachining technology [12]. The z-axis sensor is the missing piece needed for a fully monolithic 3-axis accelerometer. The symmetry of the device can be improved by adding an additional electrode above the movable proof-mass to generate equal pull-up and pull-down forces [13]. The fabrication of this additonal plate, however, adds substantially to the process complexity and is not compatible with the fabrication technology used for this work. Instead, an alternative approach to overcome the problems arising from the asymmetry of the z-axis structure with an appropriate electronic interface is chosen and will be described in Section IV.

Fig. 2 shows a close-up view of the fabricated sensing element. It consists of a 400 × 400 μm^2 proof-mass suspended above the substrate with four folded beams. The distinctly visible holes ensure complete etching of the sacrificial oxide between the silicon surface and the proof-mass at the end of the fabrication process. Combs around the periphery of the proof-mass exert an electrostatic pull-up force on the proof mass, as will be described later.

The sensitivity of the accelerometer is optimized by maximizing the inertial mass m and minimizing the spring constant k_z of the suspension in the z-direction. In practice, this demands trade-offs with sensor reliability, susceptibility to off-axis acceleration signals, and yield. Polysilicon flatness imposes an upper limit on the dimensions of the mechanical structures and hence the achievable mass, which for this sensor is approximately 0.5 μgrams, a figure that is representative of polysilicon surface micromachined sensors.

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Because of the low inertial mass, very soft springs are needed to achieve a detectable displacement of the sensor. The excellent control of dimensions that is characteristic of modern IC technologies is the key to overcoming this problem. The minimum feature width and spacings achievable in the fabrication technology used for this project are 2 and 1 μm, respectively, and in principle permit realization of springs with constants as low as 1 mN/m [14]. Such weak springs, however, are impractical because of sagging due to gravitation, susceptibility to self-resonance, and a tendency to stick to the substrate.

Sensitivity to off-axis acceleration is a further concern in the choice of a suitable suspension. Ideally, the suspension permits motion only in the z-direction, while rejecting all other inputs. The single-fold suspension chosen for this sensor (Fig. 2) exhibits excellent suppression of translation in the x- and y-directions. Its length is constrained by polysilicon warpage.

The spring constant of the sensor is found indirectly from the resonant frequencies using finite element simulation [15] and invoking the relation $2\pi f_r = \sqrt{k_z/m}$. The simulation results for the four lowest resonances are illustrated in Fig. 3. Each plot shows magnified views of the motion of the proof mass corresponding to the particular mode. The first resonance occurs for excitations in the z-direction as desired. The resonant frequency of $f_r = 7488$ Hz corresponds to a spring constant $k_z = 1.1$ N/m. A 10 mg acceleration results in only a 0.44 Å displacement and thus demands an extremely sensitive position measurement circuit. Assuming linear springs, a 360 g acceleration is needed for the sensor to touch the substrate.

The suspension rejects translations as expected but is susceptible to rotation about either diagonal of the proof-mass at 12.6 kHz. This result closely matches analytical calculations, which predict this resonance at $\sqrt{3}f_r$ [16]. The remaining modes correspond to much higher frequencies. Because of that, the displacement for a given force is much smaller, and its influence on sensor performance is negligible. The fourth resonance occurs at 64 kHz. At this frequency, the proof-mass acts no longer as a rigid body. Two opposite corners move upwards while the others move down. The finite element simulation package features a dynamic animation mode to help visualize the motion.

Aside from the reduced sensitivity, the low inertial mass of only 0.5 μgrams makes the structure susceptible to thermal noise, setting an ultimate limit on the achievable resolution of the accelerometer. Thermodynamics postulates that the thermal energy of a device equals $\frac{1}{2}k_BT$ for each mode. For example, the mean kinetic energy of the acceleration sensor in Fig. 1(a) in z-direction is $\frac{1}{2}m\overline{v_z^2} = \frac{1}{2}k_BT$. A reduction of the mass m consequently implies an equivalent increase of the average thermal velocity $\overline{v_z^2}$ and results in a white input referred acceleration noise of [17], [18]

$$\sqrt{\frac{\overline{a_z^2}}{\Delta f}} = \sqrt{\frac{8\pi k_B T f_r}{mQ_z}}.$$

In this equation, f_r is the resonant frequency in the z-direction of the structure, and m and Q_z are the mass and the Q-factor of the spring-mass system. As expected, increasing the mass reduces the Brownian noise floor, but this approach is incompatible with the size constraints of micromachined sensors. A more attractive approach consists of increasing Q_z. In this structure, the loss in the z-direction is dominated by squeeze film damping. At atmospheric pressure $Q_z \approx 1$, resulting in a thermal acceleration noise floor of approximately 120 $\mu g/\sqrt{\text{Hz}}$. Much higher Q-factors and correspondingly lower noise are achieved at reduced pressures. Q-factors as high as 80 000 have been experimentally confirmed for polysilicon structures [19] corresponding to a decrease of the noise floor by over two orders of magnitude.

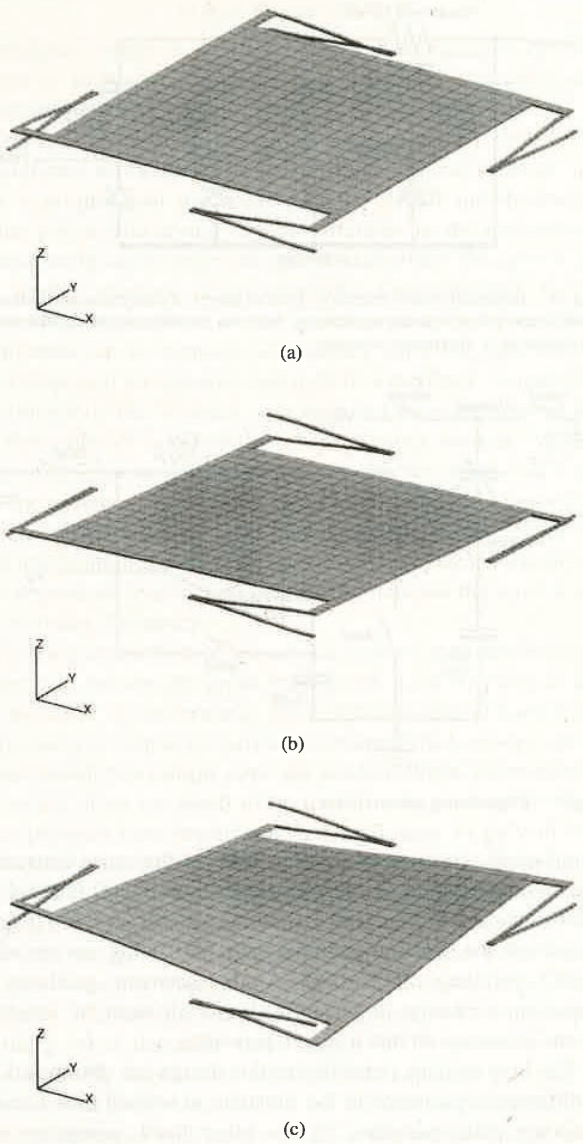


Fig. 3. Finite-element analysis of the resonant frequencies of the accelerometer. The plots show a greatly enlarged view of the motion corresponding to the (a) first mode at 7.5 kHz. (b) second mode (and symmetric third) at 12.6 kHz. (c) fourth mode at 64.4 kHz .

III. Position Sense Electronics

Acceleration is measured by detecting the change of capacitance between the proof-mass and the substrate. Fig. 4 shows a model of the capacitive interface of the sensor. An n^+ emitter diffusion implant in the p^- substrate under the

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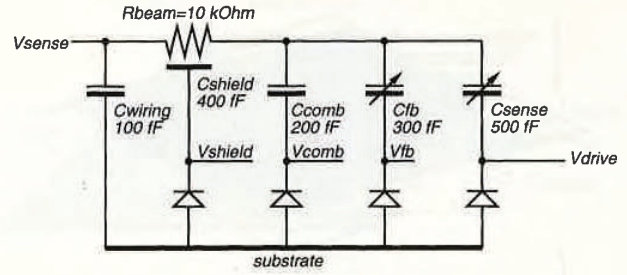


Fig. 4. Electrical sensor interface. Bottom plates of capacitors are indicated with a heavy line, and the capacitance between the suspension and the shield is shown as a distributed element.

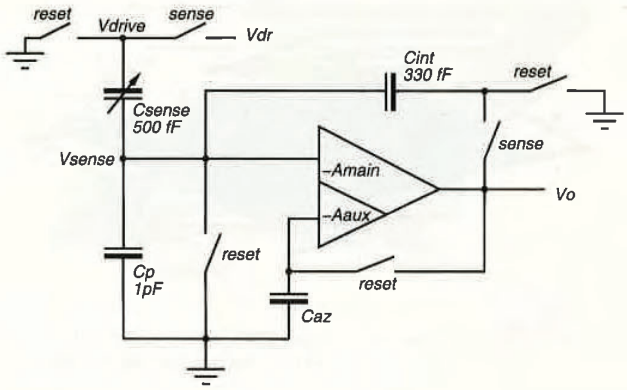


Fig. 5. Capacitance sense circuit.

proof-mass serves as the bottom plate of the sense capacitor. The nominal value of the sense capacitor is 500 fF, and its sensitivity to vertical displacements $dC/dz \approx 310\,\text{fF}/\mu\text{m}$ based on the 1.6 μm nominal gap. A 10 mg acceleration signal resulting in a 0.44 Å displacement produces a capacitance change of only 14 aF, which must be detected in the presence of much larger parasitics.

The bottom plate parasitics in this design are dominated by a diffusion capacitance to the substrate of several pico-Farads. The top plate parasitic, on the other hand, comprises the capacitance associated with a levitation comb, an electrostatic actuator used for force-feedback, wiring capacitance, and electrostatic shields, and is approximately 1 pF. Shielding is required, for example, under the suspension to prevent electrostatic actuation due to stray fields.

The capacitance sense circuitry is shown in Fig. 5. The top plate parasitics are lumped into a single capacitor C_p. The large bottom plate is driven by a voltage source in this circuit and thus irrelevant to first order. The circuit operates in two phases by first charging C_{sense} to a known voltage and then transferring the charge onto a capacitor C_{int} with known value, resulting in voltage across C_{int}, which is proportional to the size of C_{sense}. The amplifier A_{main} establishes a low impedance at its input, effectively shorting the parasitic C_p. The value of C_{int} represents a trade-off between the output level, suggesting a small C_{int}, and the achievable sampling rate, which calls for a large integrating capacitance.

Correlated double sampling is used to attenuate the flicker noise from A_{main} by storing it on C_{az} during the reset phase

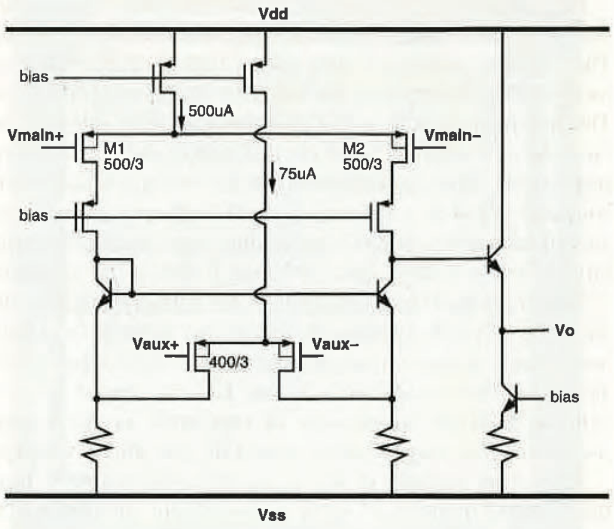


Fig. 6. Circuit diagram of the position sense amplifier.

with the help of an auxiliary amplifier with reduced gain A_{aux} [20]. In addition, the dc-potential at the sense node is also established during reset. Compared to other solutions, this approach obliviates the need for and associated noise of a leakage resistor for setting this potential [12].

The transistor level circuit diagram of the amplifier is shown in Fig. 6. The differential inputs of the main and auxiliary amplifier are labeled V_{main} and V_{aux}, respectively. A telescopic configuration is used to minimize the noise. The input transistors of the auxiliary amplifier are tied to the degeneration resistors of the load to overcome the systematic offset between the input and output of telescopic amplifiers. For the main amplifier, C_{int} stores the necessary level shift between the input and output of the main amplifier.

The noise in this circuit is the sum of the broad band noise from the amplifier during the sense phase plus the noise sampled onto C_{sense} and C_{int} during reset. Because of the small capacitor values, the latter contribution is dominant in this implementation and results in an input-referred acceleration noise with one-sided spectral density

$$\sqrt{\frac{\overline{a_n^2}}{\Delta f}} = \frac{(2\pi f_r)^2 z_0}{V_{dr}} \sqrt{\frac{2k_B T}{f_s C_{\text{sense}}} \left(1 + \frac{C_{\text{int}}}{C_{\text{sense}}}\right)}.$$

In this equation, f_s and z_0 are the sampling rate and the nominal gap of the sense capacitor, and in this design equal 500 kHz and 1.6 μm, respectively. For $V_{dr} = 0.5$ V, the noise floor is 167 $\mu\text{g}/\sqrt{\text{Hz}}$. It can be improved either by reducing the first factor in the equation, corresponding to increasing the sensitivity of the sensing element, or by decreasing the electronic noise, amounting to increasing f_s or C_{sense}. The latter is achieved preferably by decreasing the gap z_0 rather than enlarging the area of the capacitor, since this approach consumes no additional real estate and yields a double benefit in the form of a larger value of both C_{sense} and dC_{sense}/dz. Increasing the sensitivity of the sensor by decreasing its resonant frequency potentially has even greater merit. Dropping f_r from 7.5 kHz down to 1 kHz, for example, would reduce

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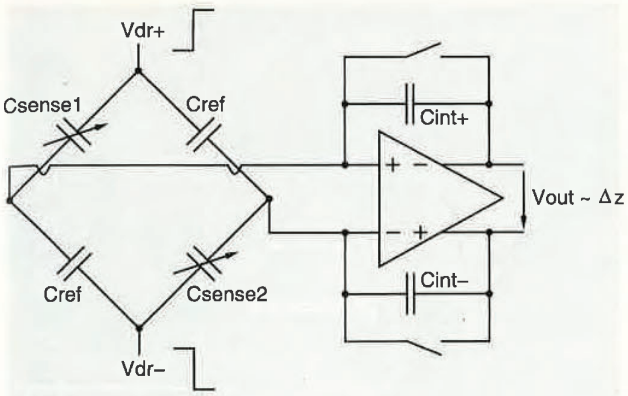


Fig. 7. Simplified diagram of a fully differential z-axis accelerometer. Two sense elements are used for capacitors C_{sense1} and C_{sense2}.

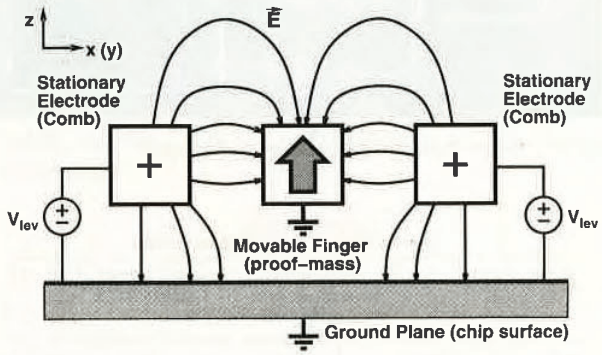


Fig. 8. Levitation comb principle.

the electronic noise floor to less than 3 $\mu g/\sqrt{\text{Hz}}$, well below the Brownian motion noise floor at atmospheric pressure. The practical problems associated with low resonant frequencies have been discussed in Section II.

The sense voltage V_{dr} used to detect changes of C_{sense} also exerts an electrostatic pull-down force. The comb-fingers arranged around the proof-mass generate an opposing force to maintain the nominal position of the sensing element. Fig. 8 illustrates the electrical field distribution between a movable and two stationary comb fingers. The silicon surface acting as a ground plane results in an asymmetric field distribution with more field lines terminating at the top of the movable finger. The result is a net pull-up force, which for small displacements is approximately proportional to the square of the applied bias [21].

The asymmetry of the z-axis sensing element results in an offset, which in this design requires external calibration. A better solution employs two sensors with their sense capacitors configured as a full bridge for a fully differential readout (Fig. 7) [22]. The sense and reference capacitors must be precisely matched. This is achieved with a dummy proof-mass anchored to the substrate. Better noise immunity of the position sense circuit and reduced drift are further advantages of this approach. It has not been pursued in this implementation because of size limitations of the sensors imposed by the fabrication technology.

IV. Force-Feedback Loop

Feedback offers a number of critical advantages in the design of acceleration sensors. The most important ones are summarized here.

The sensitivity of an open-loop accelerometer is inversely proportional to the spring constant of the suspension which in turn is proportional to the cube of the length and thickness of the polysilicon spring. Small variations in the processing consequently cause large changes in sensitivity. By operating the sensing element in an electronic force-feedback loop, this strong dependence of the accelerometer on processing parameters can be reduced substantially since for sufficiently large loop gain the linearity and drift of a feedback system are determined by the feedback path only and thus independent to the first order of nonidealities of the sensing element. Moreover, open-loop designs call for a trade-off between sensitivity and measurement bandwidth; in a closed loop accelerometer, these characteristics can be chosen independently. Sensors with low damping to decrease the Brownian motion noise floor also depend on feedback to electrically dampen the motion at the resonant frequency.

The implementation of a feedback control loop requires an actuator to restore the proof-mass to its nominal position in the presence of an external force. Electrostatic actuation is particularly attractive for surface micromachined sensors since no additional fabrication steps are needed. While electrostatic forces are often too small to be useful in larger sensors, this is no problem here because of the small mass of polysilicon micromachined devices. Forces amounting to an acceleration of the proof-mass corresponding to several hundred g's can be produced within the bounds of standard supply voltages.

In this design, a separate feedback capacitor underneath the proof-mass is used to generate a pull-down force. The quadratic relationship between the applied voltage and the resulting force demands some means of linearization. The poor matching between the parallel plate capacitor pull-down structure and the levitation comb pull-up preclude cancellation of the nonlinearity with a differential arrangement, an approach that is often used with symmetric sensing elements [12]. Instead, the feedback signal is quantized to only two levels and only the voltage across the feedback capacitor is modulated.

Fig. 9 shows a block diagram of the force-feedback loop. Together with the electronic position sense circuit and 1-b comparator, it forms an oversampled ADC where the proof-mass provides second-order noise shaping for frequencies above its resonance [23], [24]. The digital 1-b output is processed by a decimation filter analogous to those used in purely electronic implementations of oversampled converters.

Without compensation, the second-order feedback-loop is unstable. Previous designs either limit the loop bandwidth electronically to less than the resonant frequency of the sensor [12] or employ an over-damped sensor [24]. The former solution is not acceptable since the limited bandwidth interferes with oversampling. The second solution results in an elevated Brownian noise floor. In this work, a lead compensator is used for stabilization. The filter is dimensioned to provide sufficient phase lead to push the quantization noise to as high frequencies

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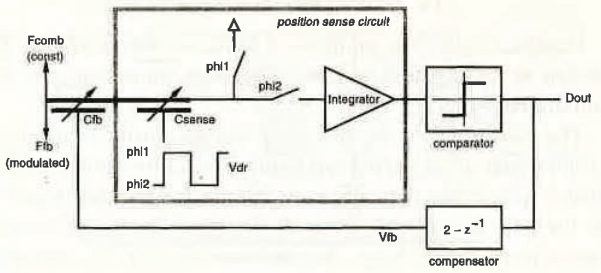


Fig. 9. Force-feedback accelerometer block diagram.

as possible. In a second-order modulator, this requirement is met when the total phase at $f_s/4$ is less than 180° [25], [18]. The compensator is implemented in the feedback path of the modulator and since its input is a 1-b signal consists of only a latch and a few gates.

Due to the high sampling rate required to suppress the sampling noise from the position measurement circuit, quantization noise is negligible in this implementation. However, the high resonant frequency of the proof-mass, which is acting here as the noise shaping filter, results in a dead-zone for small inputs. The width of the dead-zone corresponds to the minimum input required to cause the comparator output to change and is [26]

$$a_{\min} = a_{\max}\left(\frac{f_r}{f_s}\right)^2.$$

For an input range of the accelerometer of $a_{\max} = \pm 5$ g, the dead-zone width is ±9 mg. This relatively high value is unacceptable in many applications but can be reduced either by increasing the sampling frequency or by decreasing the resonant frequency of the proof-mass.

V. Measurement Results

Fig. 10 shows a die photograph of the z-axis accelerometer. The sensing element is placed in the center of the chip to minimize errors due to package-induced stress. The close proximity of the position sense integrator minimizes interconnect parasitics. The sensor and associated electronics consume less than half of the available die area of 9 mm^2. This small size demonstrates the feasibility to integrate entire systems consisting of several different types of sensors on a single die.

For performance evaluation, the accelerometer is mounted on a shaker table and excited with a sinusoidal acceleration signal. The digital output is evaluated by a computer and for calibration compared to the output from a reference accelerometer. The measured output spectrum is shown in Fig. 11. The noise floor is at 1.6 mg/$\sqrt{\text{Hz}}$, corresponding to a resolution of 11.3 mg for a 50 Hz input bandwidth. The spectrum of the noise is independent of the magnitude of the input for signals up to ±5 g.

This performance is comparable to that achieved by other monolithic accelerometers fabricated in the same [5], [6] or a similar surface micromachining technology. It is adequate for automotive applications such as active suspension as well as a number of other applications, such as tracking systems for head mounted displays.

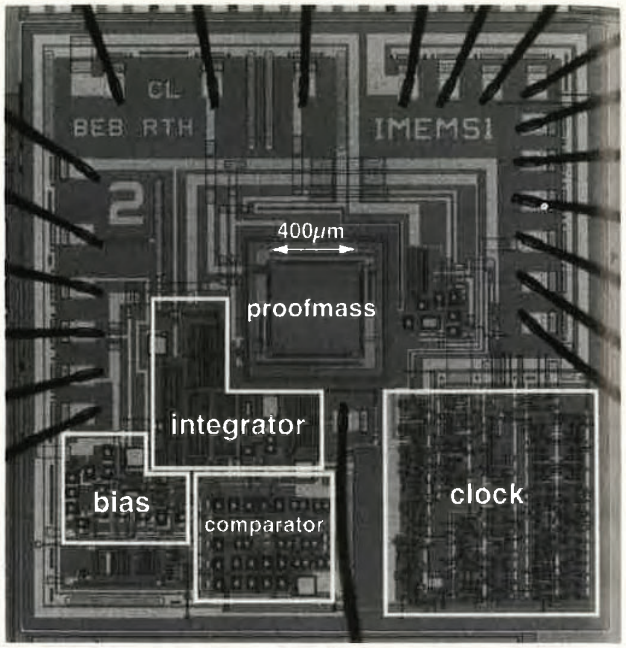


Fig. 10. Die photograph of the prototype accelerometer.

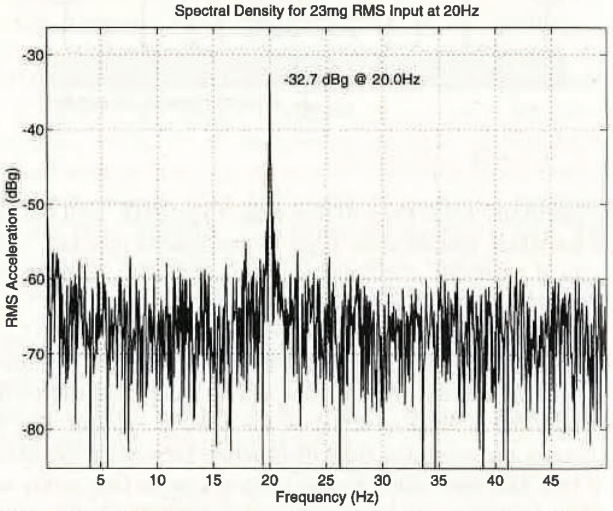


Fig. 11. Measured output spectrum for a 23 mg rms input at 20 Hz.

The noise is dominated by excess quantization noise folded into the baseband not predicted in the analysis presented above. It is caused by the delay in the electronic circuitry from the time the position of the proof-mass is measured to the time the feedback pulse is generated [18]. This delay introduces a phase delay causing the quantization noise to shift to lower frequencies [25]. The problem can be overcome with a different clocking scheme and some changes in the position measurement electronics. These changes are expected to decrease the noise floor down to a value that is close to the Brownian noise floor at atmospheric pressure, which for this device is approximately 120 μg/$\sqrt{\text{Hz}}$.

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VI. Conclusions

Cofabrication of surface micromachined sensors and electronic circuits represents an attractive and versatile technology covering a large range of devices and applications. The small form factor and possibility of integrating several different sensors on a single die constitute particularly attractive features of this approach.

The miniature scale of surface micromachined sensors results in elevated Brownian motion and electronic noise, but the achievable performance is compatible with the needs of most applications of such devices. Resolution in the milli-g range has been demonstrated in a first generation z-axis device. This figure can be improved by at least an order of magnitude through circuit improvements. Micro-g resolution is possible with vacuum packaged devices and a faster electronic circuit technology.

Acknowledgment

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Crist Lu received the B.S. degree in electrical engineering from the University of California at Los Angeles in 1992 and the M.S. degree in electrical engineering and computer sciences from the University of California at Berkeley in 1994.

In 1994, he joined Silicon Systems Inc. as a Design Engineer and has since been involved in the design of read/write channels for CD writers.



Mark Lemkin was born in Bethesda, Maryland in 1969. He received the B.S. degree in mechanical engineering from Carnegie Mellon University in 1991 and the M.S. degree in mechanical engineering from the University of California at Berkeley in 1993.

He is currently a doctoral candidate at the University of California at Berkeley where his research interests include the design of microelectromechanical systems and real time control systems.



Bernhard E. Boser (S'79–M'83) received the diploma in electrical engineering in 1984 from the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland and the M.S. and Ph.D. degrees from Stanford University in 1985 and 1988, respectively.

From 1988 to 1991, he was a member of the technical staff at AT&T Bell Laboratories, working on VLSI implementations of artificial neural networks and algorithms for automatic learning. Since 1992, he has been an Assistant Professor with the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley. His current research interests are in the areas of integrated circuits for data conversion and communication and on the design and fabrication of micromechanical systems.

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