READERS' TECHNICAL ENQUIRIES

We are unable to offer any advice on the use, purchase, repair or modification of commercial equipment or the incorporation or modification of designs published in the magazine. We regret that we cannot provide data or answer queries on articles or projects that are more than five years' old. We are not able to answer technical queries on the phone.

PROJECTS AND CIRCUITS

All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it. A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

COMPONENT SUPPLIES

We do not supply electronic components or kits for building the projects featured; these can be supplied by advertisers in our publication Practical Everyday Electronics. Our web site is located at www.epemag.com

We advise readers to check that all parts are still available before commencing any project.

Constructional Project

POCKET g-METER by BILL MOONEY

Uses a space-age chip to tell you how much g-force you are experiencing.

This portable accelerometer will tell you the g-force you experience when you break hard in your car, when you ride in a lift, or at the fairground. It is based on a tiny polysilicon micromachined sensor etched onto an integrated circuit. The earth's gravity is used as a reference standard.

As described, this is an experimental project designed as a simple introduction to the world of acceleration. The g-Meter output is in the form of a 10-segment bargraph type display, but for more accurate measurement or signal processing an output socket is provided.

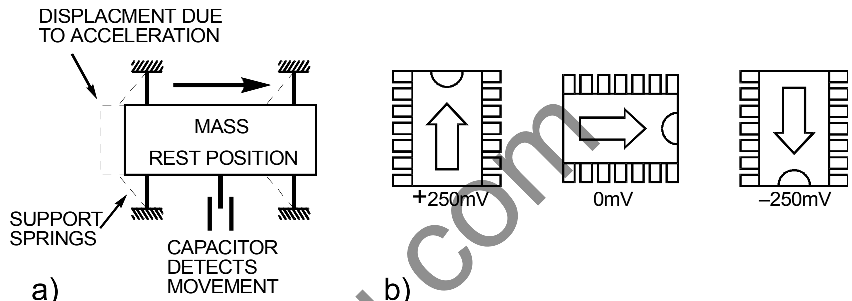
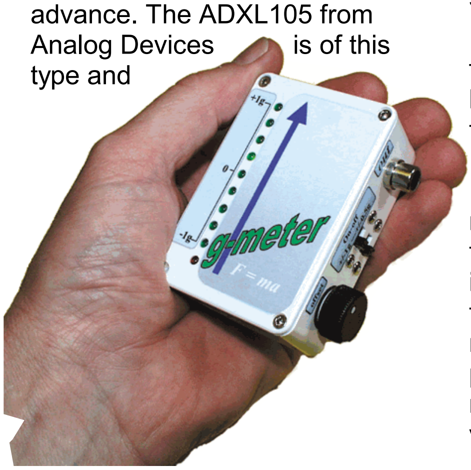


Fig.1. (a) Operating principle of the internal "beam" movement sensor and (b) influence of Earth's gravity.

ACCELEROMETERS

There are many ways of measuring acceleration involving various piezoelectric, resistive, or inductive devices, but the new micromachined silicon sensors represents a considerable advance. The ADXL105 from Analog Devices is of this type and



the surface mount package contains all the driver circuitry to make a very effective accelerometer.

The sensor is a tiny, two micrometer, beam etched onto an integrated circuit along with the detector electronics. The sensor is, in fact, a beam of polysilicon held at four points by supports of the same material, see Fig.1a. The supports can flex and so act as springs.

Inertia resulting from the mass of the beam is the basis of the detection system. If the supporting integrated circuit is moved this mass tries to stay where it is. Any acceleration therefore causes the mass to move in proportion. On reaching constant velocity or if stationary, the beam returns to its rest position.

A small differential capacitor attached to the side of the beam is unbalanced by its displacement. This unbalance results in an on-board 200kHz clock signal reaching the

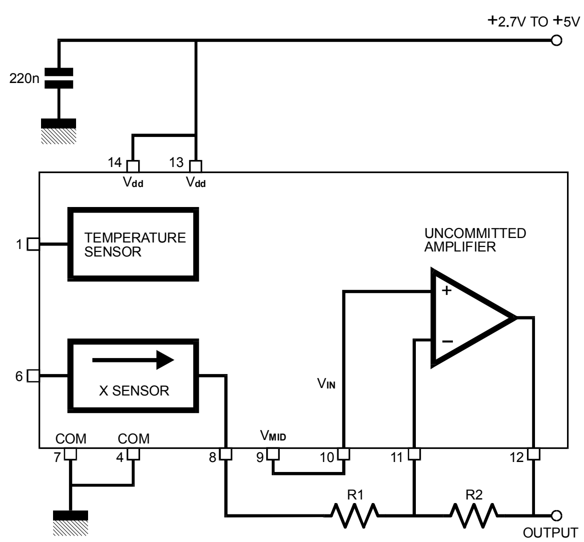


Fig.2. internal functional circuit of the ADXL105. Gain is set by values of external resistors R1 and R2.

demodulator which produces an output voltage representing acceleration.

SENSITIVITY

Originally developed specially for space research projects, micromachined accelerometers are very tough and will withstand the huge acceleration experienced by rockets. The sensing beam has a mass of 0·1 microgram and its movement can be detected down to 0·2 angstroms or about a tenth of an atomic diameter. The beam displacement-sensing capacitor is a minute 0·1pF and a change of 1aF (1 ato farad is 10^{-18}F) can be detected; real space-age stuff! The ADXL105 accelerometers, as used in this project, can detect "g" down to a couple of milli-g at frequencies from DC to above 20kHz. A particular advantage for the g-Meter is the ease of calibration. Simply turn the chip on either end to detect +1g or –1g as it senses the earth's gravity. This is a very stable reference with a value of 9·80600 $m.sec^{-2}$ at 45° latitude.

Devices like the ADXL105 can be used for tilt and inclination measurement as well as shock and vibration studies.

COMPONENTS

Resistors
R1 100k
R2 220k
R3, R4 56k (2 off)
R5 2k2
All surface mount devices (SMD), case size 1206

Potentiometer
VR1 10k ceramic "knob pot" (linear)

Capacitors
C1 200n ceramic chip, case size 1206
C2 82n ceramic chip, case size 1206
C3 100u tantalum, 4V

See also the SHOP TALK Page!

Semiconductors
D1 to D9 3mm green LED (9 off)
D10 3mm red LED
IC1 ADXL105JQC (or AQC) micro-machined sensor (SMD)
IC2 LM3914N linear bargraph LED driver

Miscellaneous
S1, S2 s.p.d.t. miniature slide switches 15mm fixing center (2 off)
SK1 phono socket, chassis mounting
B1 3V battery pack (2 x AA cells with holder)

PCB available from the *EPE Online Store* at **www.epemag.com** (code 7000269); plastic box, size 75mm x 51mm x 28mm; multistrand connecting wire (see text);

Approx. Cost Guidance Only ***(Excluding batts)*** **$56**

Multi-axis devices can be used to offset the effect of tilt, which appears as an acceleration to the sensor.

The ADXL105 single axis device was chosen for this simple project. The effect of the Earth's gravity on the output at pin 8 is shown in Fig.1b. The internal functional circuit for the IC is shown in Fig.2.

The signal from the detector has a magnitude of 250mV/g and is centered on the mid-rail voltage. An uncommitted on-board amplifier is provided for signal level adjustment and filtering. The gain is set by the selection of resistor R1 and R2 values and a variety of filtering options are possible by the addition of capacitors to the opamp feedback circuitry.

CIRCUIT DETAILS

The g-Meter is a simple experimental circuit intended to give an insight into the scope of acceleration measurement. It consists of an ADXL105 sensor directly coupled to a simple 10-segment light-emitting diode

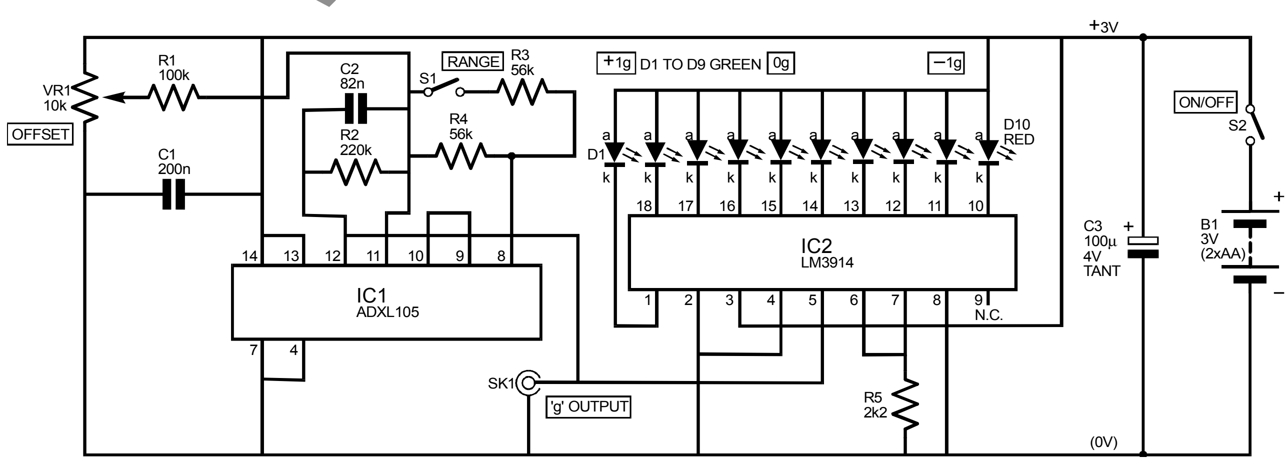
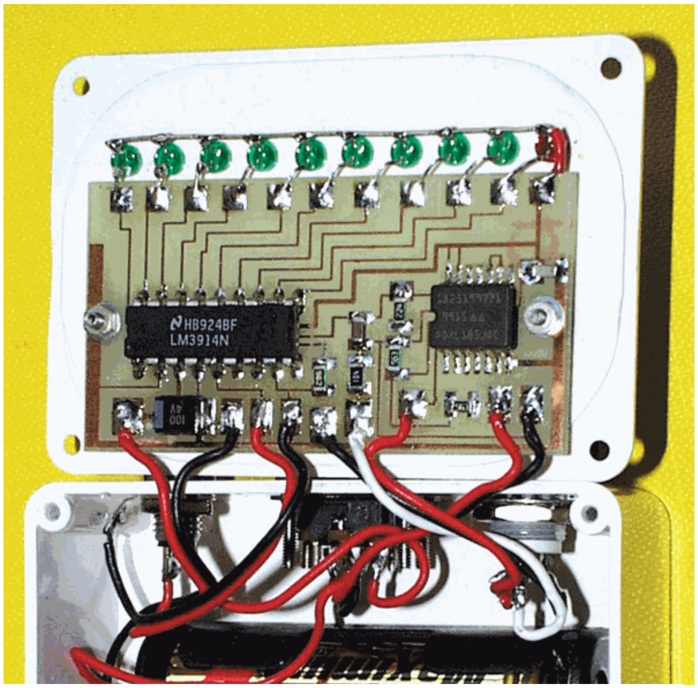


Fig.3. Complete circuit diagram for the Pocket g-Meter.



Larger-than-life view showing the tiny surface-mount components mounted on the PCB.

(LED) bargraph type display.

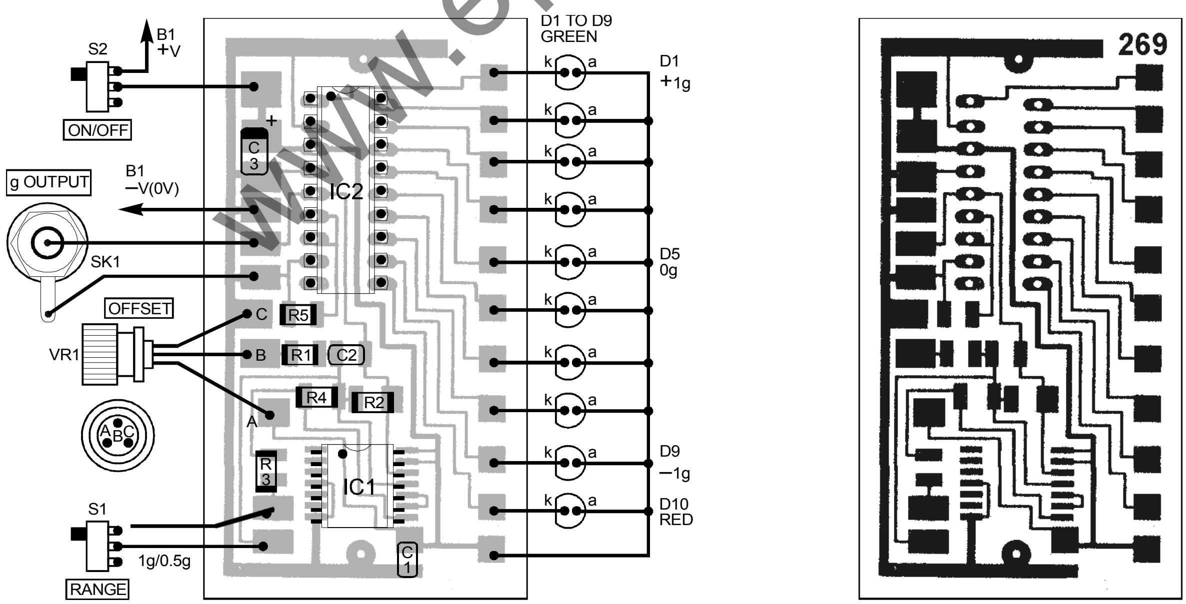
Both the LM3914 LED driver and the ADXL105 sensor will work down to 2·7V (unlike the now obsolete ADXL05 which needs 5V). The circuit can therefore be run from two AA cells.

The full circuit diagram of the Pocket g-Meter is shown in Fig.3. The signal from the detector of IC1 appears at pin 8. This is coupled directly to the uncommitted amplifier which is wired for a gain of 4x or 8x corresponding to a 2g or 1g range, which is selectable by switch S1. A very rudimentary filter consisting of capacitor C2 limits the device to a frequency response of a few Hertz (Hz) to suit this application.

The LM3914 linear LED driver, IC2, is operated in dot mode for lowest current drain. It requires an input of 0V to 1·3V for full scale operation. Therefore, the mid-rail based output from the sensor must be offset as required.

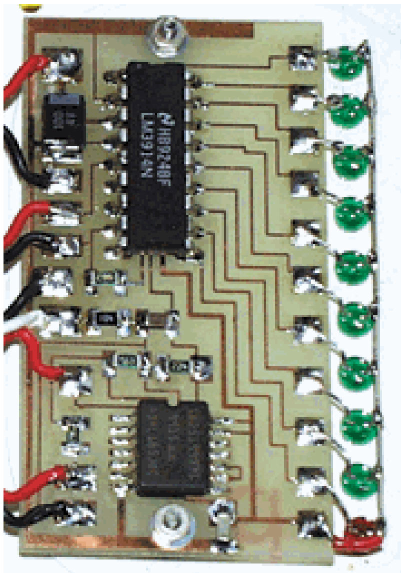
Potentiometer VR1 allows the zero-g position to be conveniently placed at LED D1, D10 or D5 with the sensor chip in any orientation. This is a most useful feature of the design and makes the g-Meter a very versatile instrument. The amplified and filtered output is made available through phono socket SK1.

In the prototype, all LEDs



PCB DIMENSIONS: 37 x 67mm / 1.45 x 2.65 in

Fig.4. Printed circuit board component layout, interwiring and (approximately) full-size underside copper foil master. Note that IC2 is also soldered to the topside tracks of this surface-mount hybrid board.



Finished circuit board bolted to the rear of the case kid.

are green except D10, which is red. This allows D5 to be set as zero g with four equal steps above and below this point. This LED also behaves differently in that higher voltage inputs leave it on so it acts as a useful indicator. Resistor R5 controls the LED brightness and can be changed at the expense of battery life.

CONSTRUCTION

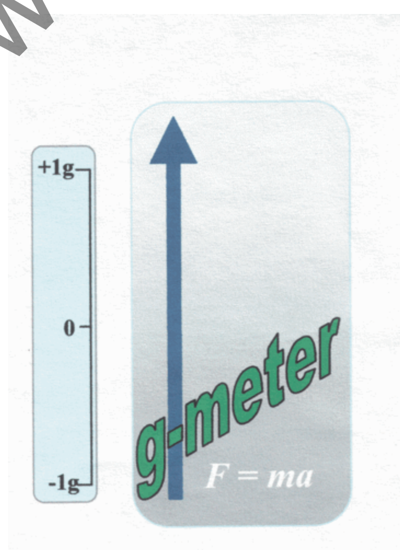
This project is a hybrid circuit in that the LM3914 LED driver, IC2, is a "standard" dual-in-line (DIL) format device. This is soldered on the upper copper track side of the printed circuit board (PCB) just like the surface mount devices. About half of the components fit on a single-sided printed circuit board (PCB).

The component layout on the surface mount circuit board (copper pads topside), together with the interwiring and (approximately) full size copper foil master, is shown in Fig.4. This PCB is available from the *EPE Online Store* (code 7000269) at www.epemag.com. If you are producing your own PCB, remember that track and components are on the same side so there is no need for the usual mask inversions.

The layout of the whole instrument is designed to cater for the "sense" of movement. So that a forward movement of the g-Meter, as you look at it, results in successive LEDs lighting up in the direction of movement, see photographs. Because of the inversion of the signal by the uncommitted amplifier in IC1, this means that LED D10 lights first, reaching D1 at maximum acceleration in this direction.

Similarly, the Offset potentiometer VR1 is wired so that a clockwise rotation "pushes" the lit LED towards D1. Thus the whole instrument is intuitive in operation.

The LED driver IC1 should be soldered in last because its pins protrude through the PCB and the board will not rest flat on the work surface. This would get in the way of the surface mount soldering process making it



Completed g-Meter showing the side-mounted components.

even more awkward in "positioning" these components.

Placing the chip components is just a matter of soldering one end first whilst holding it in place with tweezers. The free end can then be soldered with ease.

Aim to use minimal solder. This is not just to make the project look neat but results in a more flexible connection and less stress is transferred to the chip. This is particularly important for the higher value ceramic chip capacitors like C1 and C2, which are a little more delicate.

CASE PREPARATION

Before mounting the LEDs on the PCB and bolting the board to the lid of the case, the two halves of the project box should be prepared. Taking the bottom half, one side panel of the case should be carefully marked and drilled to take the phono socket SK1, the two slider switches and the miniature potentiometer VR1.

The two slide switches will need careful attention and the rectangular cutouts should be made first. The best way to do this is to mark the cutout for the lower switch, on the outside of the case, with a pencil or Biro and drill holes in the four corners, fractionally inside the marks.

Next, drill a series of holes along the guide marks to join up with the corner ones. The edges of the resulting cutout should be smoothed down with a fine file.

Now offer up the switch to the cutout so that the slider knob protrudes into the case from the outside. Mark the two fixing hole positions, remove the switch and drill the holes.

Repeat the procedure for the other switch and mount them in the case together with the other off-board components. You can, if you wish, solder leads on these components at this stage for later wiring to the PCB. If you do, make the leads sufficiently long enough to allow the lid of the case to be fully opened for battery changing.

Having completed this operation, the lower half of the box can be put to one side for later. Now for the case lid and final assembly.

FINAL ASSEMBLY

In the prototype, the 3mm LEDs protrude through 3mm holes in the lid of the project box. A sharp drill and a little skill should produce a push fit and no glue will be needed. Take care to drill the LED holes evenly spaced (6mm between centers) and in as straight a line as possible for best visual effect.

All the anode (a) leads are connected to the positive voltage line by a short length of stripped solid-core connecting wire. This is connected to the last copper pad in the line of LED connections, as indicated in Fig.4.

All the off-board controls and output socket SK1 are wired up using fine futaba wire as used for model control/servo work. It has a very flexible multistrand core and comes as a 3-way ribbon. You can, of course, use standard multistrand wire if you wish.

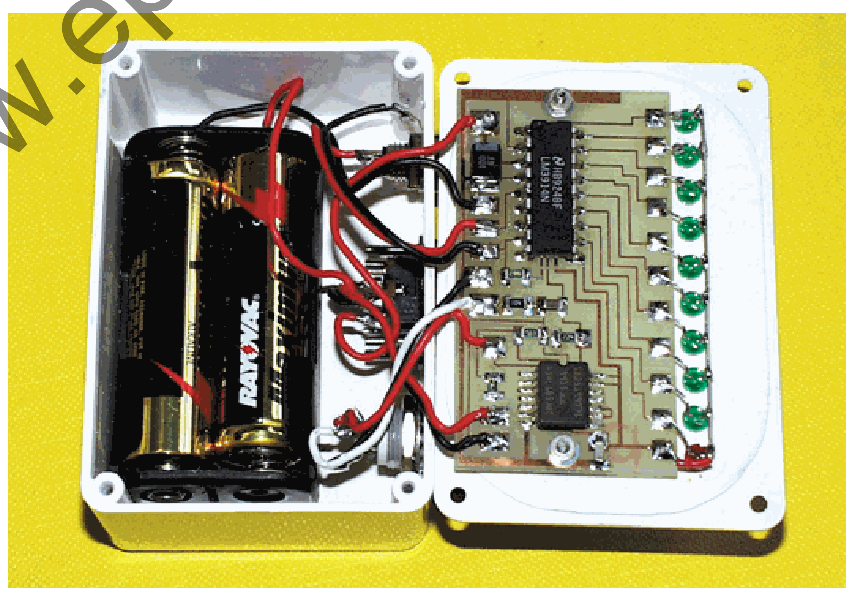
The cathode (k) lead of each LED (D1 to D10) is bent over to reach the appropriate copper pad on the PCB and soldered in place. This method is less critical than mounting the LEDs directly on the PCB.

There is little room for misalignment of the surface mount ADXL105 sensor IC as the pads are quite small, but the axis should be lined up as accurately as possible with the long axis of the PCB. The circuit board is held in place with two 2mm countersunk bolts, with extra nuts to form spacers between case lid and PCB.

For extended frequency application and if the ADXL105 were to be pushed to its full potential the mounting method would need further consideration. But the method shown is perfectly satisfactory for this low frequency application.

Finally, the LM3914 is added and its pins are soldered on the topside of the board along with the SM chips. This is perfectly in order for the DIL package which is frequently used on double-sided circuits. It is worthwhile removing the protruding leads from the reverse side of the board with a side cutter.

Returning now to the bottom half of the box, the off-board components should now be wired to the lid-mounted PCB. Give the board and wiring a final check and screw the two halves



Interwiring to the off-board components. Note the "common" connection to the LED anodes and the careful positioning of the battery holder.

of the box together. All that remains is to produce a paper/card "scale" similar to the one shown in the photographs and the unit is ready for use.

CALIBRATION

The g-Meter does not require calibration and setting it up is just a matter of checking the current consumption and adjusting the Off-set control VR1 to get the active LED on scale. The drain current should be about 5mA with no LEDs alight and about 10mA with a LED on.

A few initial checks using gravity as a reference will be worthwhile to show correct operation and demonstrate how the scale can be used.

FEEL THE FORCE

First set the range to ±1g. Then hold the g-Meter flat or rest it on a horizontal surface and, using the Offset control, adjust the position of the "on" l.e.d. to the mid position. If D5 is used as the 0g position this gives four steps to +1g and four steps to –1g.

Now turn the g-Meter to the vertical position with the arrow pointing upwards. The internal ADXL105 IC1 is now on end with pin 1 uppermost. The indicator LED should travel up the scale to the +1g position stopping with LED D1 active. This is now registering the force of gravity. Standing the device on the other end, reversing the arrow direction should result in a –1g indication.

If the offset is adjusted to indicate –1g with the g-Meter horizontal it will now cover the range of 0g to +2g. As a check, stand it on end and the active LED should reach mid-scale, which now means +1g.

Setting the range switch to the ±0·5g will drive the indicator off-scale with the meter on either end. This range can be checked by setting the indicator to –1g, LED D10 in the horizontal orientation. Then by turning the meter end-on the indicator should travel full scale to D1 covering a range of 0g to 1g.

By such manipulation a variety of operating modes can be set to suit a particular type of measurement.

A few simple experiments can now be performed. Set the range to 0 to 2g and hold the box tightly in the vertical orientation whilst jumping on the spot. A small jump will generate +0·75 to 2g. A big jump may drive the meter off scale.

But an indication of the g-force can still be gleaned from this versatile device. Simply hold it at about 60 degrees to the vertical and after resetting the off-set to the position marked –1g (LED10) you now have at a range of about 0 to 4g. Can you drive your body skyward at 4g?

Whilst sitting on a swivel chair swing around in an arc with the meter held horizontal and pointing along the radius of movement. Which way does the g-force register and why?

Monitoring the accelerations experienced during driving is revealing. A slight easing of the foot from the accelerator pedal results in surprisingly rapid deceleration due to engine breaking. Hard breaking, rapid take-off from traffic lights and excursions over hump-back bridges also produce interesting g-forces.

Too much of this in-car work can result in unwanted large deceleration so be careful or get a chauffeur. A safer way to experience smooth acceleration is by travelling in lifts but here again there can be arresting dangers. Fairgrounds also generate a wide range of acceleration experiences.

WHAT IS "g"

Before all this is understood, it is necessary to explain speed and velocity. Speed is simply the average velocity over a journey and is not very useful in physics. Velocity describes the rate at which distance is covered with time and is measured in meters per second.

Velocity is always in a straight line. Any change in velocity is achieved by applying a force to the body when it will slow down or speed up, i.e. will decelerate or accelerate. So acceleration is the rate of change in velocity, and as the units of velocity are meters per second, then acceleration is meters per second per second or m. sec^{-2}

To understand "g" we need to invoke Newton who discovered that any two masses, like you and the earth for example, experience a force of attraction called gravity. At the earth's surface this force is the same as you would feel if you were accelerated at 9·81metres sec^{-2} and is therefore given its special title of 1g.

Although acceleration is measured and mostly quoted in meters per sec^{-2} in many cases it is more meaningful to quote it in g. Acceleration (a), force (F) and mass (m) are all tied together in Newton's apparently simple relationship:

$$F = ma$$

With this we can calculate the acceleration which will be produced by the application of a particular force. A good example is a falling apple. It weighs about 100g (its mass, m) and whilst it drops from the tree it will accelerate at 1g or 9·81m. sec^{-2} (a) so that the force (F) on the apple is obtained by multiplying its mass by its acceleration.

To get the units correct the mass is measured in kilograms, in this case 0·1kg. So that the force is 0·1 x 9·81 which gives F as 9·81kg.m. sec^{-2} and this happens to be about 1 Newton of force.

To sum up, it is acceleration coupled with mass that is meaningful to us as this describes the force we feel. A jumping flea can generate huge acceleration without problems whereas the same acceleration would be very uncomfortable for a human.

The ADXL105 is used for earthquake detection, in particular for automatic gas cut-off. It will register vibrations very effectively and looking at the output on an oscilloscope can be very informative. Wooden floors are not as solid as they feel, but lets hope you don't get a chance to register an earthquake.

The g-Meter, used for tilt detection will quickly show just how effective even a low cost spirit level can be. It is surprising what can be done with this single axis detector and it shows how useful a multi-axis device might be.