

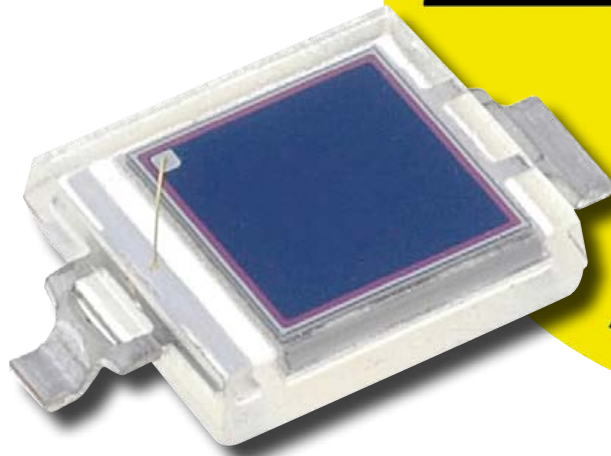
# Measure Gamma Rays with a Photodiode

## Radiation detector using a BPW34

by Burkhard Kainka (Germany)

The first device that springs to mind when thinking about measuring radioactivity is the Geiger-Müller tube. However, these counter tubes are getting hard to find and expensive, and even if you do

manage to get hold of one, you will still need to find a way to generate its operating voltage of several hundred volts. It is less well known that even a humble photodiode such as the BPW34 can be used to detect X-rays and gamma radiation.



Ionising radiation is potentially harmful to health, and it is important to minimise one's exposure to it as far as possible. A simple Geiger counter with a small glass mantle tube will not usually be adequate to detect possibly harmful radiation. The semiconductor sensor we describe below also has a relatively low sensitivity, only being able to detect fairly intense sources of radiation, but it is nevertheless an interesting device for carrying out experiments and measurements.

An advantage of using a photodiode is its small sensitive area. The background rate due to cosmic rays is very low and signals from small samples are easier to detect than with a counter tube.

### Radiation

When considering protection from radiation it is gamma rays that are the most important. They can penetrate walls and it is difficult to block them. Hard gamma rays are present in the environment all around

us and are also not stopped even by a thick wall. Alpha particles, on the other hand, only have a short range and generally cannot even penetrate a sheet of paper: this is the reason that many counter tubes cannot detect them, unless they have a very thin mica window. Beta particles have a longer range and can penetrate thin sheets of metal. Most counter tubes are mainly designed for detecting gamma rays while, within certain limitations, also being sensitive to beta particles.

### Diode as detector

The behaviour of a type BPW34 PIN photodiode is similar to that of a low-cost counter tube. Alpha particles will be stopped by the plastic enclosure of the device, whereas gamma rays pass through without problem and create many electron-hole pairs in the diode's depletion layer. If the diode is reverse-biased, almost all of the charge carriers will be drawn away: this corresponds to a small current pulse which can be amplified and processed. Beta particles can also

generate such a signal if they are sufficiently energetic to reach the depletion layer. The amplitude of the signal produced by the photodiode is considerably smaller than that normally obtained from a counter tube, and so a very low-noise instrumentation amplifier circuit is needed.

Another requirement when using a photodiode as a beta and gamma radiation detector is that light must be completely excluded, as otherwise the photocurrent will overwhelm the signal we are looking for. In our prototype we used ordinary aluminium kitchen foil as a screen.

The difference between PIN diodes and PN diodes is that the former include an extra very lightly N-doped region called the 'intrinsic', or 'i' region. This high-resistance region lies between the 'n' and 'p' regions. The result is a wider depletion layer in the diode, and hence a greater volume of semiconductor that can interact with photons. The structure is used in a photodiode in

order to obtain as many charge carriers as possible per photon, optimising the device's sensitivity.

Another way to increase sensitivity is to increase the sensitive area of the device. However, this has the disadvantage of increasing its capacitance, which reduces the (voltage) amplitude of its output signal. Commercially-available semiconductor radiation detectors have a large area and a wide intrinsic region. Simple PIN photodiodes such as the BPW34 are less sensitive than these devices, but also of course somewhat cheaper.

The BPW34 and BPX61 photodiodes are practically identical apart from their enclosures. The (cheaper) BPW34 comes in a plastic package, whereas the BPX61 comes in a TO-5 metal enclosure with a glass window. It is possible to remove this window (carefully!) to expose the chip: this will make the diode capable of detecting alpha particles.

The rays or particles must first make it through a 15  $\mu\text{m}$  thick piece of aluminium (the thickness of ordinary kitchen foil). This is no obstacle to gamma rays and beta particles, and alpha particles with an energy of 4 MeV or more will also pass through. When the particle enters the plastic of the photodiode package, deceleration radiation (German: 'bremsstrahlung') will be produced in the form of brief flashes of light, which can also sometimes be detected by the sensor. It is therefore not impossible for even the BPW34 to have some sensitivity to alpha particles.

In principle any semiconductor is sensitive to ionising radiation. It is perhaps less surprising, then, that a photodiode is sen-

sitive to radiation than that the effect has not been widely remarked on before. The effect is however well known in dynamic RAMs, whose stored data can be corrupted by incident radiation. The problem of building electronics to withstand the higher levels of radiation found in space is becoming increasingly difficult, because as structures get smaller it becomes increasingly likely that a single energetic particle can interfere with the operation of a circuit.

### Amplifier

In the literature charge amplifiers are usually constructed using a low-noise FET-input opamp as the input stage. Here we take an alternative approach: **Figure 1** shows the circuit of the sensor amplifier. Two transistors are used to amplify the signal from the photodiode. The direct-coupled amplifier automatically sets itself to a mid-range operating point, which gets a good signal-to-noise ratio from the low-noise BC549C transistors.

The transistor input of the amplifier has a comparatively low impedance, which gives good noise matching. As a result of its base-collector capacitance the first stage also operates as an integrator: this turns

the brief pulses from the photodiode into longer pulses which can then more easily be amplified.

Sensitivity can also be increased by increasing the reverse voltage on the diode. This reduces the capacitance of the diode and increases the size of the depletion layer. The voltage can be as high as 32 V, although the optimum value probably lies somewhat lower: the diode already operates well at 9 V. It is also possible to wire two or more photodiodes in parallel, and that way it is possible to achieve a sensitivity on a par with that of a small counter tube such as the ZP1310.

An oscilloscope can be connected to the output of the circuit to view the signal. Readers who yearn for the clicking sound of a 'real' Geiger counter should consult the text box 'From radiation to sound' for a suitable solution.

### Construction

The circuit can be built on a piece of breadboard (see **Figure 2**), with the photodiode on the underside (**Figure 3**). To keep light out of the sensor the whole circuit is wrapped in aluminium foil (**Figure 4**). As mentioned above, ordinary kitchen foil is

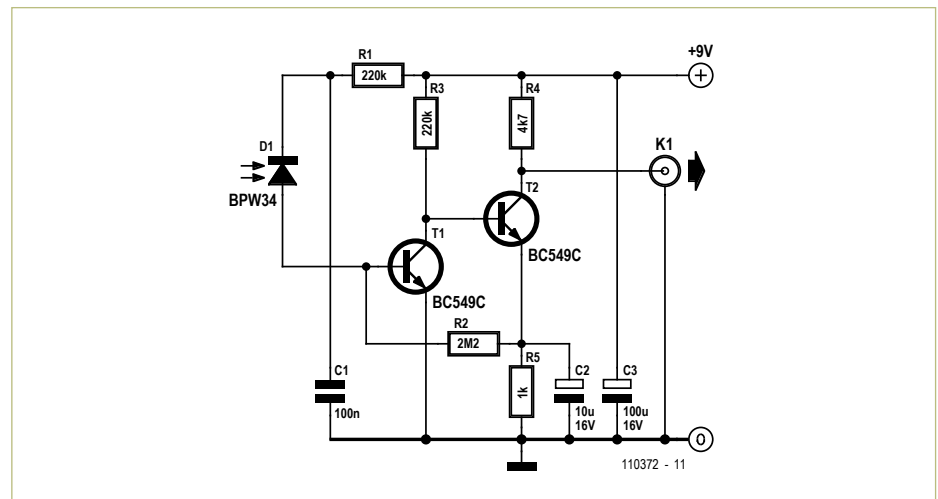


Figure 1. The amplifier circuit.

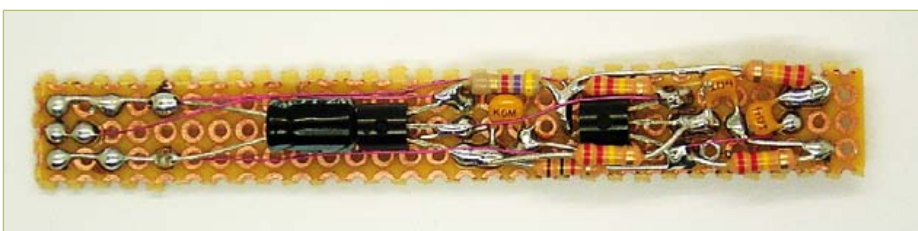


Figure 2. Prototype of the sensor amplifier.

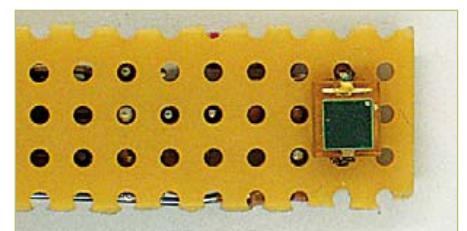


Figure 3. The sensor is on the underside of the board.

## Luminous dials

An old watch with a luminous dial is ideal for testing radiation detectors. Alternatively, a suitable alarm clock or compass might be found at a car boot sale.

Radioactive luminous paints were used until about 1965 and watch and clock faces from that time will have lost almost all of their luminosity by now. If you are not sure whether your watch is radioactive, it is possible to carry out a simple test without any electronics: all you need is a magnifying glass. In complete darkness, with your eyes fully accommodated, look at the hands under the glass. If the

paint is a radioactive mixture, you will see faint flashing and flickering: you are actually witnessing individual decays. The alpha particles produced excite the luminous paint. If you see no light or an absolutely uniform light, then there is no radioactivity present.

This test is probably only possible with luminous paints based on radioactive materials that have aged considerably, as when the paints are new there may be too many decays happening to see them individually.



Figure 4. The whole thing is wrapped in aluminium foil.

ideal for this as it is thin enough to let beta particles through. The foil also functions as electrical screening.

To avoid the foil causing short circuits, wrap the board first in insulating tape, leaving a gap for the window of the photodiode. Then wrap the assembly in foil, not forgetting to connect the foil to ground.

### Experiments and results

The best way to evaluate the results is to use a digital oscilloscope, in AC-coupled mode. A good place to start is with a vertical sensitivity of 50 mV per division and a timebase of 0.2 ms per division. Some oscilloscopes have a persistence mode which allows the results to be accumulated on the display. It is of course also possible to use an analogue oscilloscope.

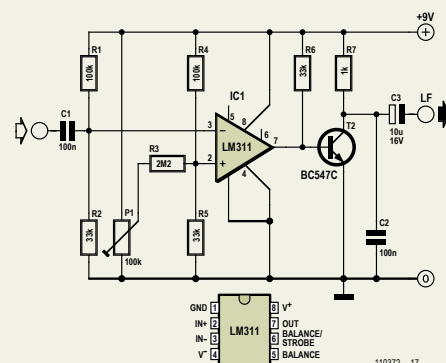
In the quiescent state a band of amplified noise about 30 mV<sub>pp</sub> will be seen (Figure 5). A gamma ray hitting the sensor will be seen as a positive pulse with a small negative undershoot following it. If strong negative-going pulses are seen it is a sign that the circuit is not screened well enough and is reacting to RF signals: the radiation we are trying to detect only causes positive-going pulses. Figure 6 shows the signal accumulated over a period of 30 s with the sensor pointing at an old pocket watch with luminous hands.

Figure 7 shows measurements taken from another radioactive sample, in this case a small piece of pitchblende (uranite), a naturally-occurring ore of uranium. Again the measurements are taken over 30 s. It is easy to see that this sample is more radioactive; but it is also possible to see a difference in the energy distribution. There are more

## From radiation to sound

A 'real' Geiger counter makes a pleasant ticking sound. Our diode sensor, on the other hand, is completely silent.

We can remedy the situation with the help of a comparator and a circuit to stretch the pulses so that we can drive a loudspeaker to make clicks. The tested circuit shown here uses a type LM311 comparator which produces a pulse on its output when the amplitude of a pulse on its input exceeds a threshold set by the trimmer. The transistor at the output stretches the pulse to make it audible. The final output can be used to drive headphones, an audio amplifier and a loudspeaker, or a PC-style active speaker.





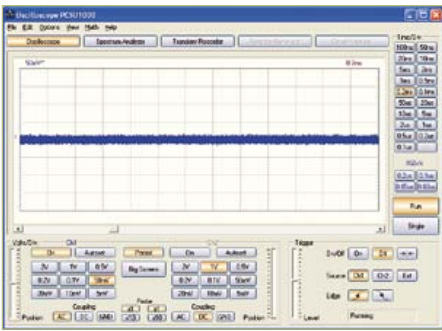


Figure 5. Circuit output in the quiescent state.

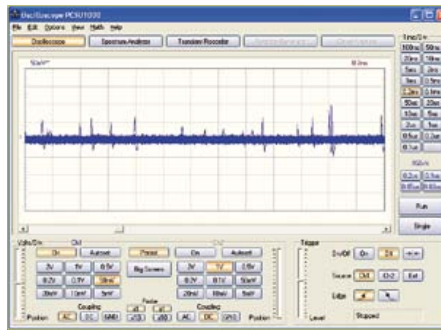


Figure 6. Readings over 30 seconds from an old watch with luminous hands.

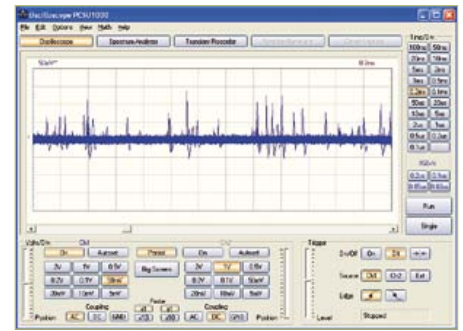


Figure 7. Readings over 30 seconds from a sample of a mineral containing uranium.

pulses with an amplitude of over 100 mV than in the case of the luminous watch. This shows that, unlike a Geiger tube, this detector can determine the energy of the individual particles. This in turn lets us make deductions about the types of nuclei that are disintegrating. In the case of pitchblende these will be elements in the uranium decay series; in the case of the luminous watch the decaying nucleus is likely to be radium.

The possibility of accumulating readings over a long time period lets us examine samples where we would expect little or no radioactivity. Here the photodiode works better than the counter tube as the background rate is practically zero. With a Geiger counter there are almost always pulses arising from cosmic rays: these hard gamma rays also affect the photodiode sensor, but because of its much smaller sensitive area these events are much rarer, and so it is eas-

ier to separate the wanted signal from the background. **Figure 8** shows readings from a sample of galena, a mineral that we would expect not to be radioactive at all. After half an hour, however, we see two clear peaks. We obtained a similar result from a sample of granite, which is known to be slightly radioactive.

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## Radon decay products

Radioactive samples for testing can be obtained directly from the environment: we are constantly surrounded by radioactive materials. For example, radon is continuously escaping from the ground. This radioactive gas decays (with a moderate half-life) producing further radionuclides, which can be collected.

Take a thin (0.2 mm diameter) piece of enamelled copper wire and stretch it out indoors. Apply a negative potential of between  $-5\text{ kV}$  and  $-10\text{ kV}$  to the wire and leave it for ten minutes. Disconnect the high voltage and then run a strip of paper along the length of the wire: you will pick up a dark line of dust that was attracted to the wire by the high voltage.

These dust particles are particularly rich in the radioactive decay products of radon. The reason for this is interesting: when the radon decays the new nuclei are moving rapidly, and are therefore

stripped of some of their electrons. This means that they have a positive charge and so are attracted to the negatively charged wire. When this 'dirty' strip of paper is held up to the radiation detector, a high level of activity will be recorded. There is no danger, however: if the isotopes had not been picked up by the wire, you would probably have breathed them in instead.

This method will let you determine which rooms in your house have more radon in them. Normally levels will be higher in a cellar or basement as the source of the radon is the earth below.

A suitable high-voltage generator was described as the 'Air Ioniser' mini project in the June 2009 edition of *Elektron* (<http://www.elektron.com/071072>). It is necessary to extend the design by a further two stages (two capacitors and two diodes) to obtain an output voltage of  $5\text{ kV}$ .

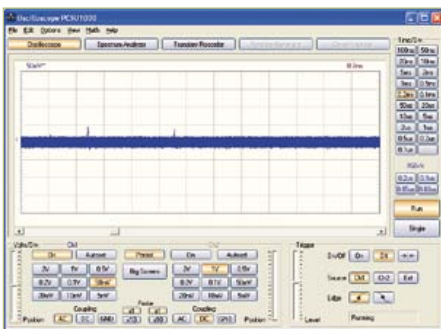


Figure 8. Readings over 30 minutes from a sample of galena.



Figure 9. A gas discharge tube with a radioactive ioniser to aid starting.

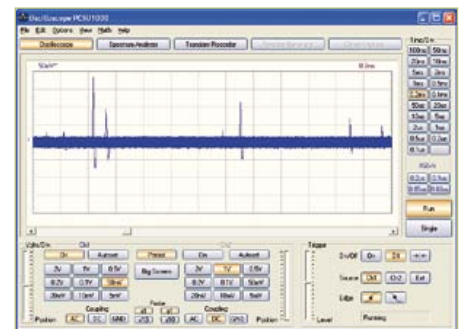


Figure 10. Readings taken from the gas discharge tube shown in Figure 9.

controls were in place can turn out to be radioactive sources. A well-known example is that certain gas discharge lamps and voltage regulator tubes rated under  $100\text{ V}$  contain radioactive substances. The author had already had suspicions about an old Russian gas discharge lamp rated at  $75\text{ V}/3\text{ mA}$  (Figure 9). There is a small metal cap welded on to the outer cover, beneath which a strange pill is visible. Beneath this is a tiny hole.

Taking readings over half an hour (Figure 10) revealed impulses with a particu-

larly high energy: all the more surprising given that the radiation had had to penetrate the glass envelope of the tube.

### Outlook

We have described the sensor and a simple amplifier for it. If the circuit is built into an enclosure, along with the comparator circuit and loudspeaker described in the text box, the result is a device that can be used in the field, for example to test minerals in a quarry. Combine the comparator with a digital counter, and the overall level of

radioactivity can be measured. A sample-and-hold circuit could be added to record energy levels, and the results could be displayed as a kind of energy spectrogram.

Another possibility is to look at taking measurements from other samples over a long period. For example, potassium chloride is a very weak beta emitter. It would be interesting to see if the photodiode can detect it.

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