MICROCONTROLLER BASED SYSTEM FOR RADON CONCENTRATION MEASUREMENT

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Abstract: the paper presents a method for monitoring radon concentration in air using a detection chamber as transducer, an embedded system based on ATmega16 microcontroller for measuring the transducer output and a GPRS modem for sending measurement data to a remote center.

Keywords: microcontroller, AVR, embedded system, radon, remote monitoring

1. INTRODUCTION

Radon is a radioactive noble gas, member in the decay chain of uranium. Being very diffuse gas it emanates from soil and rock with even small content of uranium and its descendants, into air. Radon from air can be breath in and is the second cause of lung cancer after smoking [1]. Thus high concentrations of radon can be very dangerous and constant monitoring is indicated.

Indoor exposure to radon is generally associated with increased health risks; at around 3000 cancer affections/year. In 2005 respectively 2006, two big pooled studies (European and American) clearly showed the risk of lung cancer due to radon exposure to indoor radon for all population [2]. In the outside air, concentration depends on soil, air currents, etc. and varies between 7-26 Bq/m^3. Health risks are very low. High concentrations are found near uranium mines. Inside buildings, higher concentrations were measured in the basement and the ground floor depending mainly on soil type, construction materials and insulation from soil [3].

In this paper is presented a system for monitoring radon concentration. The system is composed from a detection chamber with photodiode transducer, an analog block for detecting and forming spikes, a central processing unit with ATmega16 microcontroller, a 128x64 pixel graphic LCD display and a GPRS modem. The block diagram of the system is presented on Figure 1.

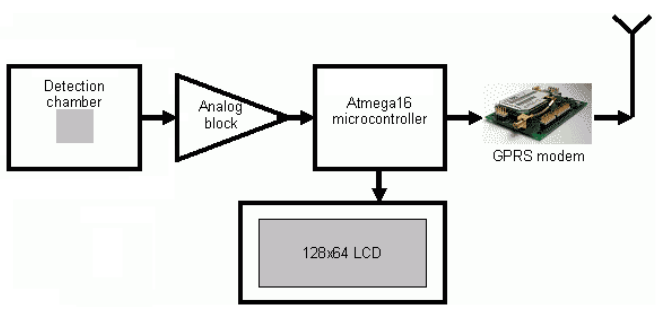

Fig. 1. Block diagram of the radon measuring system.

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2. SYSTEM SIMULATION

Two possible methods for radon concentration measurement were examined, the first one based on signal integration, the other one based on pulse counting.

The simulations showed that for measuring low concentrations of radon such as those occurring in the Brașov area, the integration method is inadequate for practical uses. The simulation results were verified through practical implementation of both variants, thus proving the validity of the simulation.

2.1. Simulation of integration principle

The proposed model of the integration measurement method achieved with SIMULINK® is shown in Figure 2. A pulse generator simulates the occurrence of a radioactive particle at a rate of one particle/10ms, with the signal amplitude of 10^{-7} A and the duration of 0.01% of the period, that is 10µs. The noise is simulated with a random numbers generator, with the noise signal amplitude of 10^{-8} A. The photo-cell is simulated with a current source and a 10MΩ load resistor.

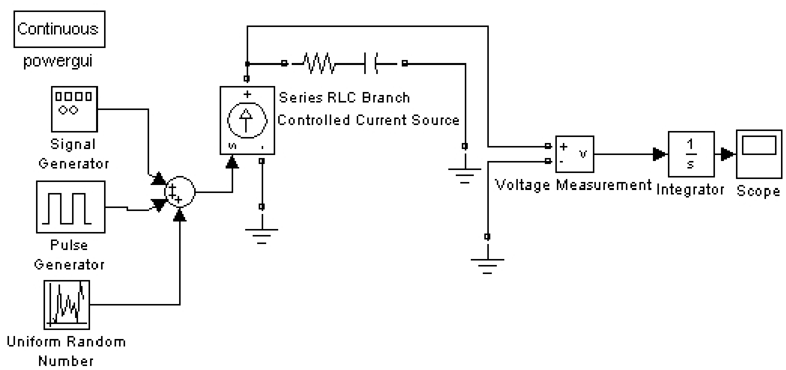
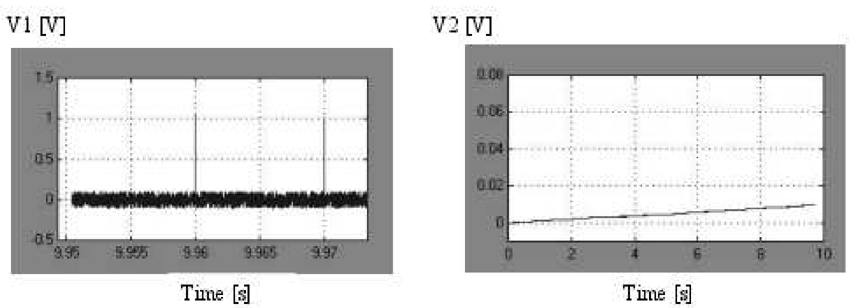


Fig. 2. SIMULINK® model of the integration measurement method.

Figure 3.a presents the signal variation over time at the output of the photo-cell combined with noise in the absence of the integrator circuit (V1). The short-duration pulses (10µs) mixed with a noise signal 1/10 the amplitude of the useful signal can be easily observed. Figure 3.b presents the integrated output signal, V2, (10ms period, 10µs pulse duration. The final value of the output voltage of $1.06x10^{-3}$ V, is affected by a 6% noise error.



a) b)

Fig. 3. The integrated output signal:
a) pulses and noise before integration, b) integrator output voltage.

For lower gas concentrations, say of one particle occurring every 100ms, the error is already of 60%, which is unacceptably large. The error increases as the pulse frequency decreases (fewer particles over time). Likewise, the error will increase as both pulse duration and amplitude are decreasing (clearly the output error depends on pulse energy).

This simulation demonstrates that, for a pulse frequency of one pulse/hour, given the case of low radon concentration measurements, the integration method is impractical. However, for verification purposes, a circuit based on the integration method was built. The practical circuit has confirmed the simulation; the cumulated noise significantly reduces the accuracy of radon concentration measurement.

2.2. Simulation of the pulse counting principle

The simulation schematic diagram for the pulse counting measurement method is shown in Figure 4. The measurements are deemed perturbed, and therefore, beside the source of useful pulses, two more sources were introduced, a source of random noise that simulates the internal noise of the photo-element and a sinusoidal source that simulates the 50 Hz perturbations arising from the AC power mains. A pulse generator simulates the low amplitude pulses produced by electrical discharge processes and a second pulse generator simulates the high amplitude calibration pulses.

Following considerations resulting after simulation should be taken into account: the integration measurement method is more adequate when compared to the pulse counting measurement method in several aspects, but unfortunately it may be applied for high discharge pulse rates (pulses/ time unit) only, whereas the measurement of low radon concentrations is associated with a small number of discharges over one day.

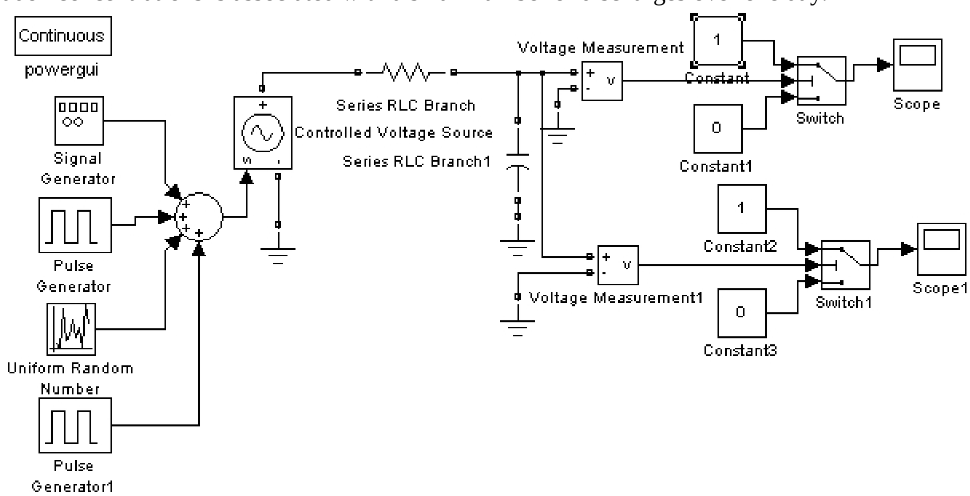


Fig. 4. Pulse counting method simulation schematic diagram.

Through integration, the measurement noise level rises over time causing the saturation of the analog integrator circuit. The pulse counting method is therefore more adequate for low concentrations measurement and it was successfully implemented, however by resorting more to the microcontroller's resources [4, 5]. The conclusions of the work team have also found confirmation in literature [6], which presents measurements on low radon concentration levels.

3. THE DETECTION CHAMBER

It is an electrostatic chamber where air can circulate almost freely through a particle filter which eliminates all solid particles. This way only radioactive element that can enter is the gaseous radon. Alpha particles from radioactive decay are measured on a photo-sensible element placed on the middle of the cathode. Electrostatic field between the anode and cathode drives alpha particles into this photo-sensible element (usually a PIN photodiode). The internal structure of the detection chamber is presented on Figure 5.

The LED is used to generate a very low intensity light, just enough to pre-bias the photodiode, increasing its sensitivity to alpha particles. Every alpha particle that hits the surface of the photodiode generates a current pulse on the output proportional in amplitude and duration with the energy of the alpha particle (typically 6 - 7.7MeV for radon).

As only radon can enter into the detection chamber, the number of current pulses caused by alpha particles give the concentration of radon in decays/second/volume or Bq/m^3.

Typical concentrations of radon in open air are 10 - 50 Bq/m³. Indoors this concentration can be higher due to stillness of air and possible radioactive content of building materials. EU regulations state a 400 Bq/m³ limit for safe level of indoor radon.

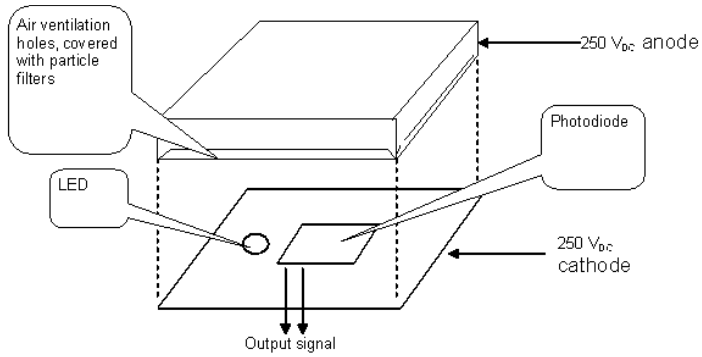


Fig. 5. Detection chamber.

4. THE ANALOG BLOCK

The analog block is responsible of forming the current pulses generated by the alpha particles hitting the photodiode into digital pulses that can be counted by the microcontroller. The output signal from the photodiode is first fed into a differential amplifier with current input and voltage output. The amplified signal is then fed into two Schmitt-trigger comparators. These two comparators are responsible for detecting whether the pulse from the photodiode is from radon or not.

If the amplitude of the pulse is lower than the first threshold then no digital pulse is generated, and if it is higher than the second threshold than both comparators generate a pulse. Both cases are ignored. Only the pulses on the output of the first comparator for which no pulse is present on the output of the second one are counted as radon decays.

5. THE CENTRAL PROCESSING UNIT

Built around the ATmega16 microcontroller it is responsible for counting radon decays, displaying information locally and sending it through serial link.

The ATmega16 microcontroller has the following features used by this system:

- 16kB of flash – used almost entirely for storing the software;
- 1kB SRAM;
- 512B EEPROM – used for storing short term radon data;
- 3 timers – one of them is used for the base timing of the system, the other two are used for counting pulses from the radon detector;
- UART – used for communication with the GPRS modem;
- 32 IO pins – 15 is used for the LCD display, the others are used by internal peripherals like UART and timers.

The main functions of the software in the microcontroller are the counting, the displaying routines and the communication with the GPRS modem. The counting is done by using a timer in counter mode. In this mode the timer is incremented on the falling edges of a signal connected to an input pin.

There is another timer running in capture mode which enables us measuring the time between events on the input. This way is used for two reasons:

- a normal pulse from a radon decay has a duration in a predefined region (experimentally determined to be around 1300 - 1400µs), if a pulse is much longer or shorter it is invalidated;
- if many pulses arrive in short proximity they are also invalidated as they are much likely to be produced by noise than actual radon decays.

Also if there is a pulse on the second input (meaning a high amplitude pulse on the photodiode) the pulse on the first input is invalidated. The counted values are processed on a hourly basis. The time base is generated by a third timer. For radon level information two readings are considered: a short term and a long term average.

For the short term reading a circular buffer of 256 byte is used. Every hour the counted value for the last hour is stored in the last position of this buffer. The short term value is the average of this buffer. This means that short term readings give the average radon level of the last 10 days approximately. The buffer for the short term readings is placed in the EEPROM along with the pointer to the last element, so in case of a power glitch the saved counts won't be lost.

For the long term reading a single 32 bit variable is used (also stored in the EEPROM) where all hourly data is summed together, which along with the number of hours (stored in a 16 bit variable) gives an average value of radon levels for the last 7.5 years. This value is reset after this time is elapsed.

For displaying the radon levels locally a 128x64 pixel graphic LCD is used. The display has its own controller (KS107-108 type) which communicates through a 8 bit parallel port and 6 control lines. The display is configured in 2 segments of 64x64 pixels each of 8 lines by 64 columns of groups of eight pixels placed vertically. This gives the option of having 8 lines by 21 columns text display of standard 7x5 characters (although these characters have to define in a look-up table in the microcontroller.

The microcontroller implements software routines for displaying text strings. In our case the short term and long term readings and the uptime is displayed as presented on Figure 7. There is also a possibility to display graphically the evolution of the short term reading of the radon values.

For this every value from the last 100 hours is converted into height where a pixel will be displayed as in Figure 8. GPRS communication is realized with a GPRS modem connected to the UART of the microcontroller. Data transmission is initiated hourly, after the short term and long term calculations are made.

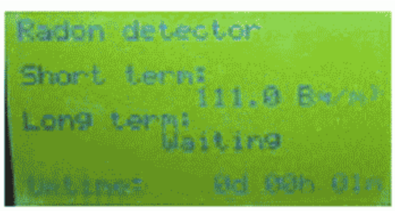


Fig. 7. Text display.

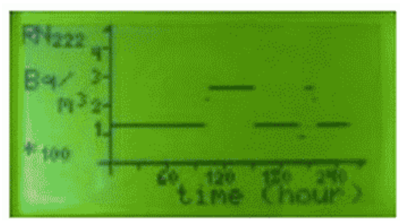


Fig. 8. Graphical display.

For transmitting the radon data a GM862-GPRS type modem is used. This modem has a SIM card slot where a SIM which enables GPRS communication must be inserted. The modem implements the Easy GPRS standard which involves internal TCP/IP stack and connection handling. This enables a simple connection to a server PC by using standard AT commands. The AT commands used include:

- a command for setting GPRS properties of all connections – issued once at power-up;
- a command for setting authentication data (like username and password) – also issued once at power-up;
- a command for setting connection parameters (like IP and port number) – also issued once;
- a command for start dialing and connecting to the server – issued whenever a new transmission is necessary and the connection no longer exists.

Connecting the microcontroller to the modem is done through a RS232 cable. This involves using a MAX232 at the microcontroller and a MAX3232 at the modem to convert to RS232 levels. This was preferred against directly connecting the modem to the microcontroller (through a 5V-3.3V level shifter) because the detection chamber tends to be very sensitive to electromagnetic interference so the modem was placed in separate housing. First a predefined dialing string is sent over the UART for connecting to the server. After this the answer from the modem is compared to the expected string (for the successful establishment of the connection). If the connection is established the microcontroller sends the following information:

1. hexadecimal representation of the current count for the last hour;
2. hexadecimal representation of the sum of the short term buffer (16bit value);
3. hexadecimal representation of the long term count (32 bit value).

After the sending of this data the connection is terminated with the sending of a predefined AT command.

6. EXPERIMENTAL RESULTS

Several parallel measurements have been done with an alternative method for the validation of the proposed measurement system. Both Radon measurement results with Safety Siren 3 (USA EPA Evaluated) system and 2 ENEA alpha-track detectors and also with the proposed measurement system were compared and plotted in Figure 9.

The obtained values prevailed from 6 to 6 hours (thin line for Safety Siren 3 and thick line for the proposed system) are similar to those obtained from the alpha-track detectors- 108 Bq/m^3 and 125 Bq/m^3.

The implemented solution for the pulse counting principle is unable to detect the type of the captured radioactive particle since the analog circuitry alters the pulse shape.

At present, a discriminator system is being developed using a microcontroller with a higher sampling rate along with a modified version of pulse capturing.

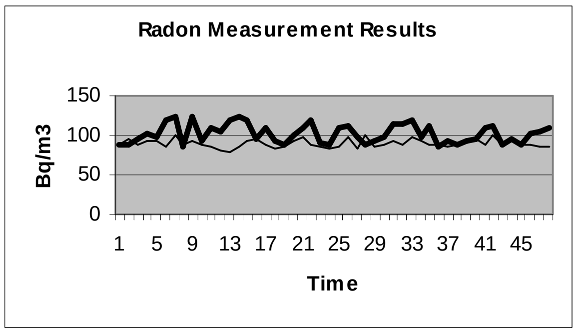


Fig. 9. Radon Measurement Results.

The system provides a quick response when the imposed limit of Radon concentration in air exceeded while the computer acquires real-time measurement data from several networked instruments.

7. CONCLUSIONS

The resulted radon monitor is presented on Figure 10. The measurement data was satisfactory compared to other radon detectors and was also capable of transmitting data to a central computer for long term monitoring of radon levels in multiple locations.

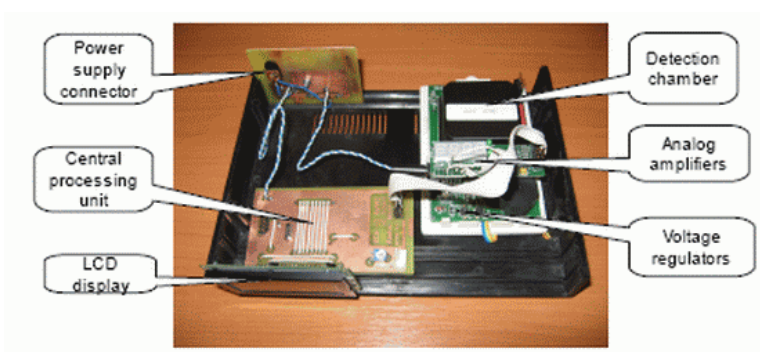


Fig. 10. The radon monitor.

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