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# LOW NOISE AMPLIFIER FOR ZnS(Ag) SCINTILLATION CHAMBER

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Warszawa 1998

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**Wzmacniacz o niskim poziomie szumów dla komory scyntylacyjnej ZnS(Ag)**

W raporcie opisano nowy wzmacniacz impulsów, który może być wykorzystywany do pracy ze standardowymi fotopowielaczami sprzężonymi z komorą scyntylacyjną ZnS(Ag). Wzmacniacz skonstruowano opierając się na scalonym wzmacniaczu operacyjnym LF 356N. Składa się on z niskoszumowego przedwzmacniacza ładunkowego i układu formowania impulsu celem optymalizacji stosunku sygnału do szumów. Niestabilność temperaturowa wzmocnienia wynosi ≤ 0,05%/°C. Zakres dynamiczny amplitudy sygnału wyjściowego jest równy +7 V. Prezentowany wzmacniacz jest wykorzystywany w głowicy pomiarowej do pomiaru komór Lucasa o pojemności 0,17 L, opracowanych w Zakładzie Aparatury i Metod Izotopowych IChTJ, w laboratoryjnych badaniach zmierzających do opracowania metod i mierników koncentracji radonu w powietrzu. Wzmacniacz może być również wykorzystywany do pomiaru promieniowania jonizującego za pomocą innych scyntylatorów sprzężonych z fotopowielaczem. Na wyjściu wzmacniacza impulsów znajduje się dyskryminator impulsów o regulowanym progu dyskryminacji. Sygnał wyjściowy wzmacniacza oraz impulsy z wyjścia dyskryminatora wyprowadzane są na zewnątrz wzmacniacza.

**Low noise amplifier for ZnS(Ag) scintillation chamber**

A new pulse amplifier that can be used with standard photomultiplier tubes coupled with a ZnS(Ag) scintillation chamber is presented. The amplifier based on an IC operational amplifier LF 356N consists of a low-noise charge sensitive preamplifier and pulse shaping circuits for optimisation of signal to noise ratio. Temperature instability is ≤ 0.05%/°C. Dynamic range for linear output signals is equal to +7 V. The presented amplifier is used in a measuring head for 0.17 L Lucas chambers developed in the Department of Nuclear Instruments and Methods of the INCT in laboratory investigations aimed to develope methods and instruments for measurement of radon concentration in the air. The amplifier can also be employed for measurement of ionization radiation by means of other scintillators coupled to PM tube. The amplifier is followed by a pulse discriminator with adjustable discrimination level. The amplifier output signal and discriminator output pulses are fed to external devices.

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## 1. INTRODUCTION

A new low-noise amplifier for the ZnS(Ag) scintillation chamber (Lucas cell) has been developed for a measuring head designed to measure radon concentration in the air by means of 0.17 L Lucas cell in laboratory investigations aimed to elaborate methods and gauges for measurement of radon concentration in the air. The Lucas cell coupled to photomultiplier tubes operates as a detector of alpha particles emitted by radon and its short lived decay products Po-218 and Po-214 that are a measure of radon concentration in the air [1-4]. The presented amplifier is employed in two measuring heads shown in Figs 1 and 2 employing two different PM tubes.

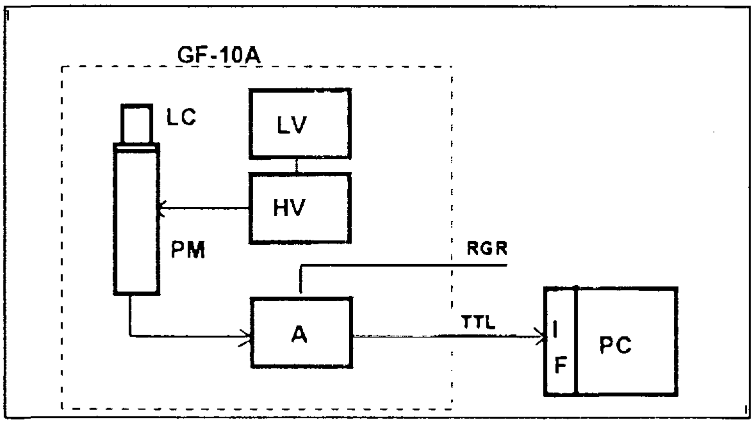


Fig. 1. Block diagram of the GF-10A measuring head for determining radon concentration: LC - Lucas cell KS-10 or KS-11, PM - photomultiplier tube FVS-300, HV - high voltage power supply, A - low noise pulse amplifier followed by a pulse discriminator, LV - low voltage (+5 V) power supply for HV, IF - computer interface, PC - personal computer, RGR - analog pulse from amplifier output, TTL - TTL pulse from discriminator output.

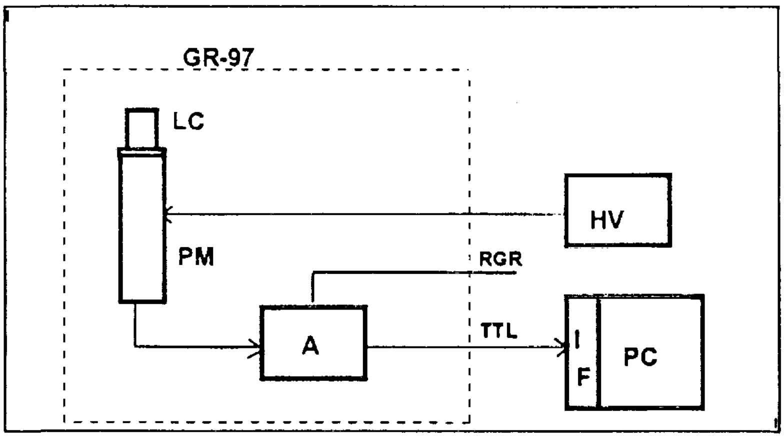


Fig. 2. Block diagram of the GR-97 measuring head for determining radon concentration: LC - Lucas cell KS-10 or KS-11, PM - photomultiplier tube EMI-966B, HV - high voltage power supply, A - low noise pulse amplifier followed by a pulse discriminator, IF - computer interface, PC - personal computer, RGR - analog pulse from amplifier output, TTL - TTL pulse from discriminator output.

The TTL pulses from the discriminator are fed to a computer interface where they are counted by a programable 16 bit counter. In both cases the low voltage +5 V and +12 V for the amplifier is taken from the PC.

## 2. FUNCTIONAL DIAGRAM AND CIRCUIT DESCRIPTION

The functional diagram of the new low noise amplifier is shown in Fig. 3. The amplifier consists of a charge sensitivity preamplifier (A1, $R_f$, $C_f$), a differentiation network with Pole/Zero cancellation (PZ, $R_d$, $R^*$, $C_d$), and an active integrator (A2, $R_1$, $R_2$, $R_3$, $C_1$, $C_2$).

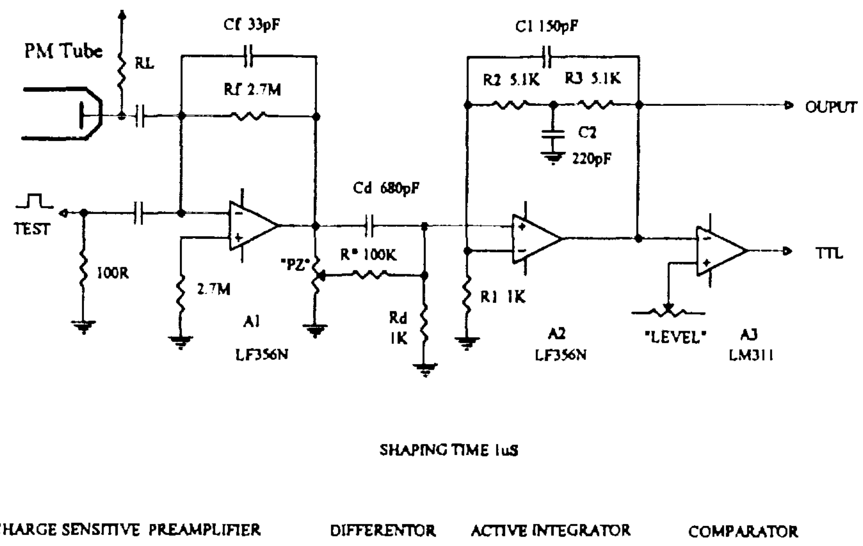


Fig. 3. Functional diagram of low noise pulse amplifier.

The filter has a constant shaping time of 1 μs and gain of 11. The amplifier constructed on the basis of op-am LF 356N with a large slew rate, low noise, low bias current, low offset, low driff and a high open-loop gain allows to improve characteristics of the device. The amplifier is designed and calculated as in [5,6]:

The input signal of the preamplifier is calculated according to the relation:

$$V_{in}(t) = 1 - e^{-t/\tau_\Phi} \tag{1}$$

where: $\tau_\Phi$ is the decay time constant of the scintillation. For ZnS(Ag) scintillator $\tau_\Phi = 0.2$ μs. If $W_1(t)$ is the transfer function of the charge sensitivity preamplifier, then its Laplace transform is given by the equation:

$$W_1(p) = -\frac{pR_fC_n}{1 + p\tau_f} \tag{2}$$

where: $\tau_f = R_fC_f$ is a feedback time constant. Thus the output pulse of the charge sensitive preamplifier is described by the relation:

$$V_1(p) = V_{in}(p) \times W_i(p) = -R_f C_n \times \frac{1}{1+p\tau_f} \times \frac{1}{1+p\tau_\phi} \tag{3}$$

The second term in eq. (3), the so called integration of input current in the feedback capacitance $C_f$. The third term represents the input signal of the preamplifier with the time constant $\tau\Phi$. Original signal is given by:

$$V_1(t) = -\frac{C_n}{C_f} \times \frac{e^{-t/\tau_f} - e^{-t/\tau_\phi}}{1-\tau_\phi/\tau_f} \tag{4}$$

Therefore, the output pulse of the preamplifier has a rise time depending on decay time constant $\tau\Phi$ of the scintillator, but its fall time is defined by the feedback time constant $\tau_f$. The Pole/Zero cancellation circuit is located at the output of the charge sensitive preamplifier. Its output pulse, without undershoot of differentiation network with Pole/Zero cancellation, is defined as:

$$e_1(p) = V_1(p) \times G_d(p) \;=\; -\frac{C_n}{C_f}\tau_d \times \frac{1}{1+p\tau_\phi} \times \frac{1}{1+p\tau_d} \tag{5}$$

where: $\tau_D = \frac{R^* R_d}{R^* + R_d} \times C_d$ is a differentiation time constant, and $G_d(p)$ is transfer function of differentiation network with Pole/Zero cancellation. By letting:

$$p + \frac{1}{\tau_f} \;=\; p + \frac{k}{R^* C_d} \tag{6}$$

the undershoot of the pulse is cancelled. In this case the k value should be kept within the limits $1 \geq k \geq 0$.

The active integrator amplifier [5] with transfer function:

$$W_2(p) = \frac{1 + \frac{2pR_2C_1}{K_0}\left(1 + \frac{C_2}{C_1}\frac{R_1+R_2}{2R_1}\right) + p^2C_2C_1\frac{R_2^{\,2}}{K_0}}{1 + 2pR_2C_1 + p^2C_1C_2R_2^{\,2}} \tag{7}$$

where: $K_0 = \frac{R_1 + 2R_2}{R_1}$ is the gain of the integrator, $\tau_I = R_2C_2$ is integration time constant, and $C_2 = 1 \div 1.5\ C_1$; $R_2 = R_3$. Thus, the output pulse of the amplifier has a Gaussian approximation shape. Its rise time depends on the integration time constant $\tau_I$ of the active integrator, but the fall time is defined by the differentiation time constant $\tau_D$. Typically, the differentiation time constant is set equal to the integration time constant, i.e. $\tau_D = \tau_I = \tau$. Then, shaping time $\tau$ of 1 μs is chosen for minimum Equivalent Noise Charge (ENC).

It should be noted that the ENC of the transfer function of this filter is lower than the ENC of the transfer function of the simplest filter network having one differentiating and one integrating stage CR-RC which usually can be used for scintillation detectors. In this case the

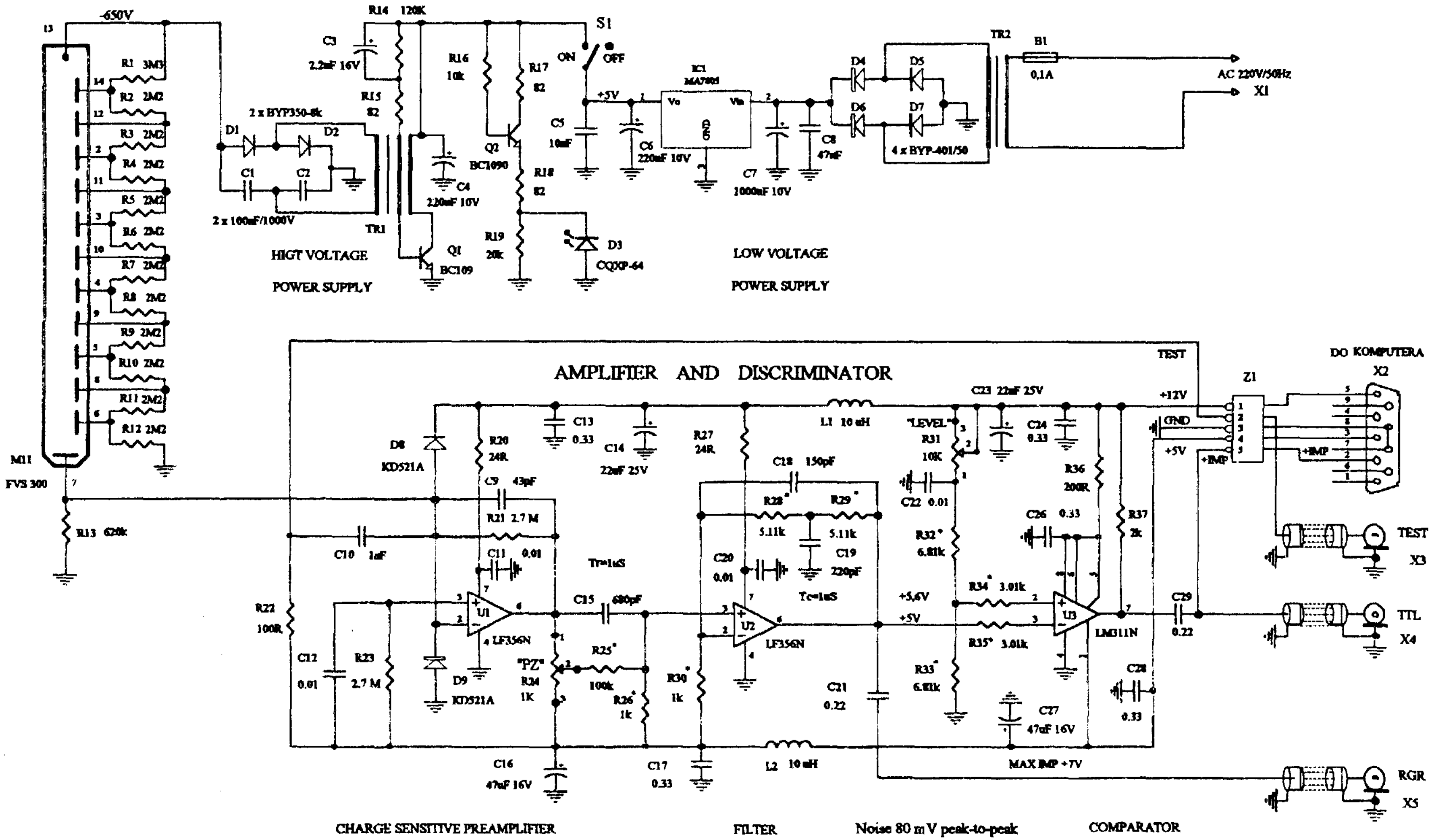


Fig. 4. Measuring head GF-10A

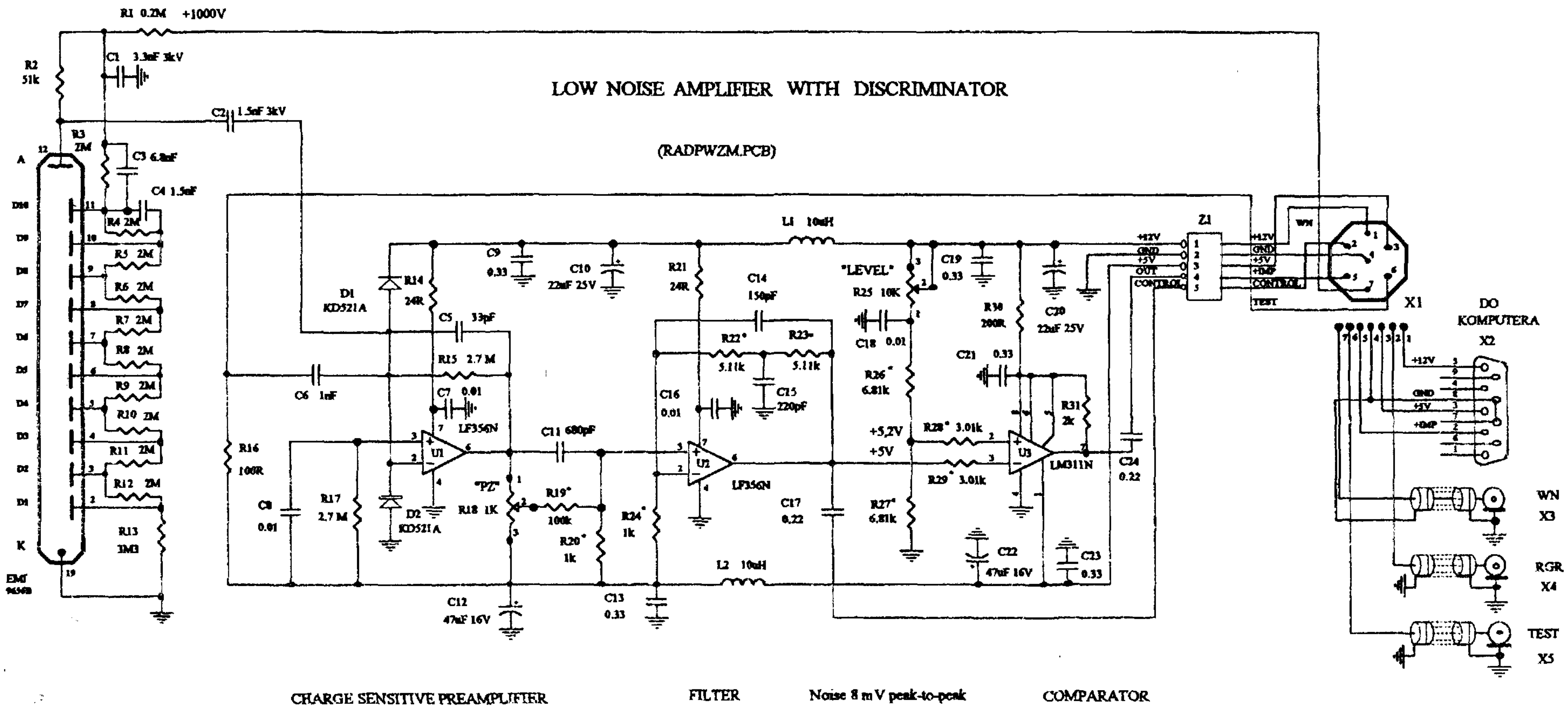


Fig. 5. Measuring head GR-97

noise of the detector, i.e. the shot noise resulting from the dark current $I_D$ and the output current $I_L$ (noise in signal) of the PM tube and Johnson noise of load resistor $R_L$, is greater than the total noise of the preamplifier, therefore the feedback resistor $R_f$ should be selected as small as possible. 2.7 MΩ was choosen. The feedback capacitance $C_f$ has the value of 30 pF-40 pF depending on the maximal amplitude of the output pulse. The output of the amplifier "OUT" provides positive unipolar pulses which can be used for spectroscopic measurements. Temperature instability is less than 0.05%/°C. Dynamic range for linear output signals is equal to +7 V. P/Z cancellation is possible with good resolution.

The discriminator A3 is constructed on the basis of the comparator LM 311. This discriminator provides TTL logic pulse when the positive edge of the amplifier output pulse crosses the level threshold setting. The output TTL of the discriminator is fed to a counter in the computer interface. The whole circuit is housed in a metallic shield box to eliminate external electromagnetic interference.

Detailed schematic diagram of the amplifier in GF-10A measuring head is shown in Fig. 4. The PM tube FVS 300 has a photocatode size of 25 mm and is supplied by -650 V. Load resistor R13 of the PM tube has the value of 620 kΩ. The described amplifier is consisting of a charge sensitivity preamplifier (A1, $R_{21}$, $C_9$), a differentiation network with Pole/Zero cancellation ($R_{24}$, $R_{25}$, $R_{26}$, $C_{15}$ ), and an active integrator (A2, $R_{28}$, $R_{29}$, $R_{30}$, $C_{18}$, $C_{19}$), and the comparator (A3). The input of a charge sensitivity preamplifier is connected directly to the anode of the PMT. The resistor $R_{24}$ adjusts the pulse at the output of the amplifier, without undershoot and the resistor $R_{31}$, adjusted as to get the required discrimination level. For 0.6 V discrimination level the voltage at pin 2 of the comparator (A3) is set exactly +5.6 V. The discriminator generates pulse every time the output pulse of the amplifier crosses the level threshold setting. The output of this discriminator "TTL" is nominally +5 V and is connected to the personal computer through the connectors Z1 and X2 or to the counter through the connector X4. The output of the amplifier through the connector X5 "RGR" can be used for spectroscopic measurements.

Fig. 5 shows the schematic diagram of the measuring head GR-97. This device is consisting of the ZnS(Ag) scintillation chamber (Lucas cell) LC, the PM tube EMI-9656B, the designed amplifier and personal computer PC equipped with computer interface IF. PM tube EMI-9656B with a photocatode diameter of 50 mm is supplied by +1000 V through the connector "WN" X3 from the HV power supply ZWN-21, produced by POLON. Load resistor R2 of the PM tube has the value of 51 kΩ. The amplifier is connected to the anode of the PM tube through the capacitance C2. The resistor $R_{18}$ adjusts the output pulse of the amplifier without undershoot and the resistor $R_{25}$ is calibrated so that exactly +5.2 V is set a pin 2 of the comparator A3 (0.2 V discrimination level). The output "TTL" of the discriminator is connected to a personal computer PC through the connectors Z1, X1 and X2. The amplified signal can be used for spectroscopy measurements through the connector "RGR" X4.

## 3. MAIN PARAMETERS

### 3.1. Measuring head GF 10A

| | |
|---|---|
| • ZnS(Ag) scintillation chamber: | KS-10 or KS-11 |
| • Photomultiplier tube: | FVS 300 |
| • High Power Supply: | -650 V |
| • Preamplifier: | Charge sensitive amplifier |
| - Feedback Capacitance: | 43 pF |
| - Feedback Resistance: | 2.7 MΩ |

- Rise Time: 30 ns
- Fall Time: 120 µs
- Filter: Semigaussian shaped
  - Shaping time constant: 1 µs
  - Output: Unipolar, positive, +7 V maximum
  - Gain: 10
  - Pulse amplitude: ≤ 6 V from α particles of Lucas cell
  - Output noise: ≤ 80 mV p-p
  - Temperature instability: ≤ 0.05%/°C
  - Pole/Zero cancellation: with high resolution
- Discriminator
  - Output: TTL max width 10 µs
  - Level threshold: +600 mV
  - External Power Supply Voltage: +12 V and +5 V dc from PC
  - Mains: 220 V 50 Hz for high voltage power

### 3.2. Measuring head GR-97

- ZnS(Ag) scintillation chamber: KS-10 or KS-11
- Photomultiplier tube: EMI-9656B
- High Power Supply: +1000 V from External Power Supply Voltage type SEWN-21, POLLEN
- Preamplifier: Charge sensitive amplifier
  - Feedback Capacitance: 33 pF
  - Feedback Resistance: 2.7 MΩ
  - Rise Time: 30 ns
  - Fall Time: 100 µs
- Filter: Semigaussian shaped
  - Shaping time constant: 1 µs
  - Output: Unipolar, positive, +7 V maximum
  - Gain: 10
  - Pulse amplitude: ≤ 2.5 V from α particles of Lucas cell
  - Output noise: ≤ 8 mV p-p
  - Temperature instability: ≤ 0.05%/°C
  - Pole/Zero cancellation: with high resolution
- Discriminator
  - Output: TTL max width 10 µs
  - Level threshold: +200 mV
  - External Power Supply Voltage +12 V and +5 V dc from PC

### 3.3. Application

- The described amplifier is used in the Department of Nuclear Instruments and Methods of the INCT in the measuring heads for laboratory investigations aimed at the elaboration of methods and instruments for measurement of radon concentration in the air.
- The amplifier can also be employed in gamma spectrometry with other scintillators and other PM tubes.

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