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Design and Construction of a Preamplifier for Research Reactor Control System Using Russia's Neutron Detectors

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Abstract: This paper presents the design and construction of a preamplifier device for Research Reactor Control System, using Russia's Neutron Detectors of ionization and fission chambers. In this work, the preamplifier device which consists of a wide range Current to Frequency Converter block used with a compensation ionization chamber type KNK-3 to measure the thermal neutron flux in the range of $1x10^6 \div 1x10^{11}$ n/cm^2.s, a Pulse Preamplifier block used with a fission chamber type KNK-15 to measure the thermal neutron flux in the range of $1x10^0 \div 1x10^6$ n/cm^2.s, and a Power Supply block, was designed and tested in different conditions in the laboratory and at Dalat Nuclear Research Reactor (DNRR). Obtained results show that, the above blocks have almost design specifications as equivalent or better in comparison with the same function blocks of the DNRR's Control System which were designed by the former Soviet Union. They also meet the utilization requirements as well as the experimental and training purposes.

Keywords: *Dalat Nuclear Research Reactor (DNRR), Instrumentation and Control (I&C), Fission Chamber (FC), Compensation Ionization Chamber (CIC), Pulse Preamplifier (PP), Current to Frequency Converter (CFC).*

I. INTRODUCTION

The original DNRR's I&C system was designed and manufactured by the former Soviet Union and put into operation in November 1983. This system is divided into four main parts [2, 5]: neutron flux control system (NFCS), reactor data display system (RDDS), control logic system (CLS), and process and instrumentation system (PIS). The NFCS measures the power and period of the reactor; giving out analogue signal proportional to the unbalance between the reactor and the setting powers; and giving out alarm and scram signals on power and period for each measuring channel. The NFCS system consists of three identical and independent electronic units, namely, the information acquisition and processing units (IAPU). The neutron flux is measured over ten decades $10^{-8} \div 1.2x10^2$ %Pn, Pn = 500 kWt) and is covered by three overlapping measure ranges by nine individual measuring channels (3 channels in each IAPU):

- Source range (SR), $10^{-8} \div 10^{-2}$% Pn;
- Intermediate range (IR), $10^{-3} \div 10$% Pn;
- Power range (PR), $1 \div 120$% Pn.

To control the neutron flux of the reactor, nine neutron detectors with gamma compensation (6 fission chambers type KNK-15 and 3 compensation ionization chambers type KNK-3) were used. The KNK-15 chambers are operated in the pulse mode for the SR and IR ranges, while the KNK-3 chambers are used in current mode for the power range. After the modernization and refurbishment project during 2005-2007 with the replacement of neutron measurement and

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signal processing parts of the original I&C system, two individual measuring channels (SR and PR) of IAPUs were kept for the experimental purposes.

In order to master the DNRR's I&C system not only for managing and safety operation of the reactor but also for the development of human resources in serving nuclear power program in the future, in the framework of the MOST's research project during 2013-2014, we have studied on the design and construction of the new preamplifier device consisted of a wide range Current to Frequency Converter block, a Pulse Preamplifier block and a Power Supply block, and used the Russia's Neutron Detectors of the old IAPUs mentioned above. Main obtained results of the studies are presented and discussed in this paper.

II. DESIGN AND CONSTRUCTION OF THE PREAMPLIFIER DEVICE

A. The detectors

Two types of KNK-3 and KNK-15 detectors of the old IAPU's were used for testing, calibration and evaluation of the new designed preamplifier device. Technical specifications of these detectors are given in Table I and Fig. 1 [3, 4]. These detectors are placed in the dry channels outside the reactor core without the surrounding radiation shielding structure and tested with the different levels of reactor power.

Table I. Specifications of KNK-3 and KNK-15.

KNK-3 ionization chamber	KNK-15 fission chamber
- Diameter: 51mm, length: 163mm; - Gas fill: 95% He + 5% N; - Neutron sensitive material ^{10}B; - Absolute value of sensitivity: + For neutrons: current - not less than: (3.3-3.46) x10^{-15} (A.cm^2.s / neutron); + For gamma-rays - no more than: 1.3x 10^{-12} · A.R^{-1}.h - Own background 1x10^{-11} A; - Capacitance 300pF; - Voltage between electrodes ±500V; - Temperature no more than 573°K;	- Diameter: 51mm, length: 260mm; - Gas fill: 96% Ar + 2% N+2%He; - Neutron sensitive material ^{235}U; - Absolute value of sensitivity for neutrons in pulse mode :(0.95-1.15) ^{3} (pulse.cm^2.s / neutron); - Own background 1x10^{-8} A; - Capacitance 360pF; - Voltage between electrodes ±500V; - Temperature no more than 573°K;

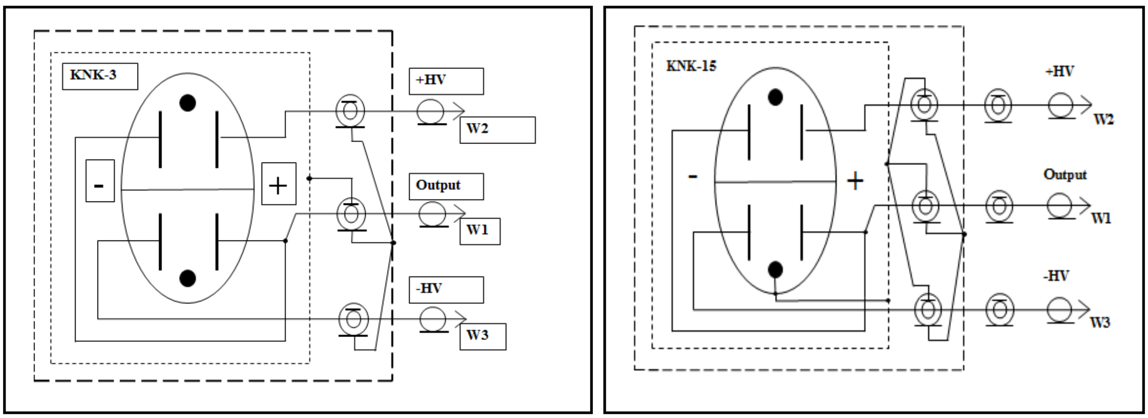


Fig. 1. The diagram of KNK-3 and KNK-15 detectors.

B. Pulse Preamplifier block [1]

1. Design description

Pulse Preamplifier block is intended for amplification of paraphrase current pulses from KNK-15 detector, for discrimination of noise pulses and for generation of pulses caused by neutron radiation. Its structural diagram is shown in Fig. 2.

In order to increase its noise immunity, after preamplifier D1 (D1 is a voltage sensitive amplifier, which used transistor common base configuration), amplifier is divided into two channels: the channel of useful signals amplification (D3, D5) and the channel of noises separation (D2, D4). Amplification sections of both channels are built on operational amplifiers, and communications between them are organized in such a way that in one channel useful paraphrase signals are amplified in maximum extent, and in other channel - inphase noise pulses are separated.

Discriminator D7 is used for separating useful signals from noises which amplitude is less than the amplitude of useful signals. By means of discriminator D6, noise pulses comparable by amplitude with useful signals are selected. Pulses from discriminator D6 are generated at univibrator UV and interlock passing of noise signals by means of passage circuit (PSC). Output signal is pulse frequency which is in proportion with neutron flux. Counting rate metter (CRM) is used for automatically changing discrimination threshold U_{th2} to reduce noise pulses. It plays an important role for more rejection of noise pulses caused by the pulse pile-up. This is an advanced design to expand the frequency range of input pulses from neutron detector. In the checking mode, generator of pulses (GP_{ch}) is started by trigger from a power supply (V_{ch}).

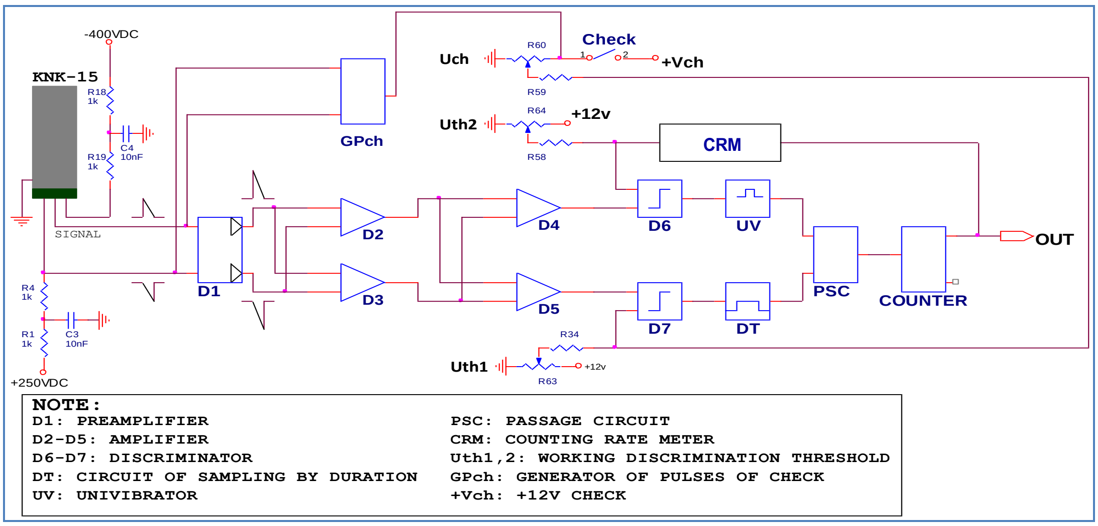


Fig. 2. The structural diagram of the pulse amplifier.

2. Testing and results

In the laboratory:

The designed Pulse Preamplifier block has been tested and calibrated in the laboratory for correction of important parameters such as: the gain of preamplifier, discrimination thresholds and range of operating frequency, etc. The Pulse Preamplifier was also tested in many conditions of temperature and humidity in the Programmable Temperature and Humidity Chamber (KEJIAN KJ2091 No.15-226). The testing diagram is shown in Fig. 3, and the relation between input and output pulse frequency is shown in Fig. 4.

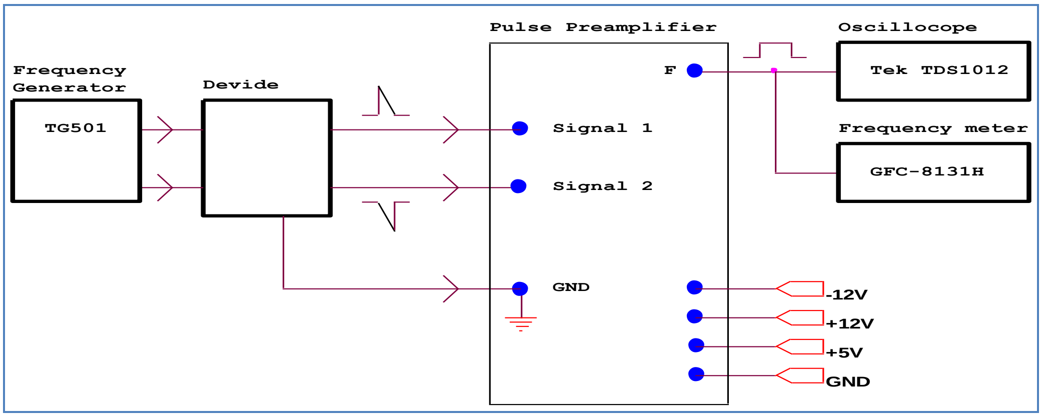


Fig. 3. Testing diagram for the pulse preamplifier block.

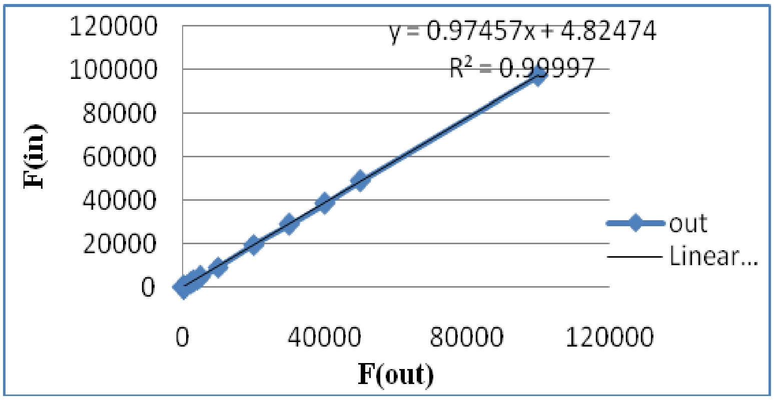


Fig. 4. The relation between input and output pulse frequency.

At the reactor:

The Pulse Preamplifier block was connected to the KNK-15 detector of the source chanel No.1 and tested at some reactor power levels from 10^{-5} to 10^{-2}% Pn (Fig. 5). The testing results and the relation between power level and output pulse frequency of the Pulse Preamplifier block are shown in Fig. 6. In the range of power levels from 10^{-5} P_n to 10^{-2} %P_n, output pulse frequencies are in good proportion with the reactor power levels.

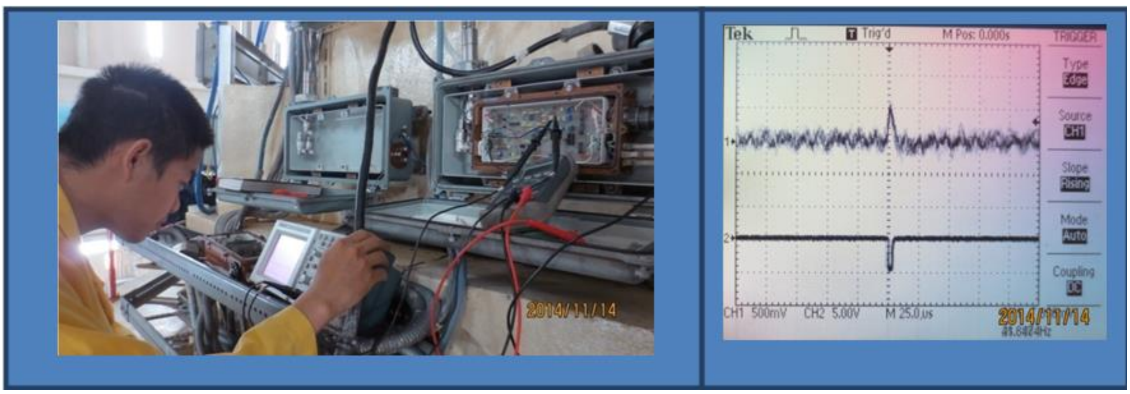


Fig. 5. Testing of the Pulse Preamplifier block at the DNRR.

Power levels (%P_n)	F (Hz) ±10 Hz
1.00E-05	98
5.00E-05	485
1.00E-04	970
5.00E-04	5.200
1.00E-03	10.765
5.00E-03	56.534
1.00E-02	98.723

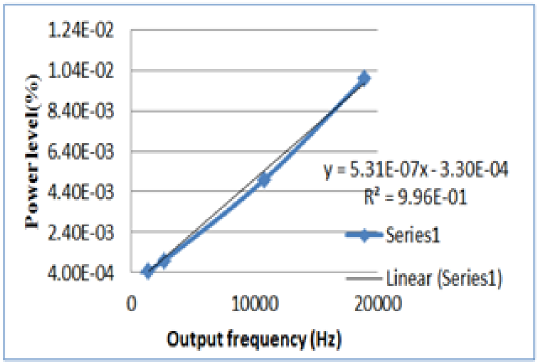


Fig. 6. The relation between power and frequency.

3. Main specifications of the Pulse Preamplifier block

- Sensitivity: 1 cps/*n;*
- Measurement range of thermal neutron flux: 0,1 ÷ 2.10^5 *nv;*
- Range of output frequency: 0.1 Hz ÷ 250 kHz;
- Pulse amplitude: +12V;
- Power supply: +12VDC/ 400mA, -12VDC/ 200mA and +5VDC/300mA.

C. Current to Frequency Converter block

1. Design description

The Current to Frequency Converter (CFC) block has been designed and developed based on the balanced charge integrating techniques with the structural diagram is given in Fig. 7.

The input current (I_in) from KNK-3 detector is charged for capacitor Cin, included into negative feedback circuit of operation amplifier (Amp). When the voltage at the output of integrator achieves the value equal to the threshold of the comparator, the Comp actuates and the output signal from the Comp triggers univibrator UV.

At the output of the univibrator, pulse of the positive polarity with the duration determined by a resistance R1 and a capacitor C1, starts the operation of discharge circuit and the capacitor Cin is discharged. The rheostart R_{conv} is used for fine regulation of the conversion coefficient.

In "Test" mode, potential +12V is supplied to relay Re, through the contacts of relay current I_ch is applied to input of converter via resistors Rch1 and Rch2. The current value is selected in such a way that output pulses of the converter have fixed frequency equal to 25 kHz.

Compensation resistors Rcomp1 (smoothly) and Rcomp2 (discretely) are used for compensation of background current.

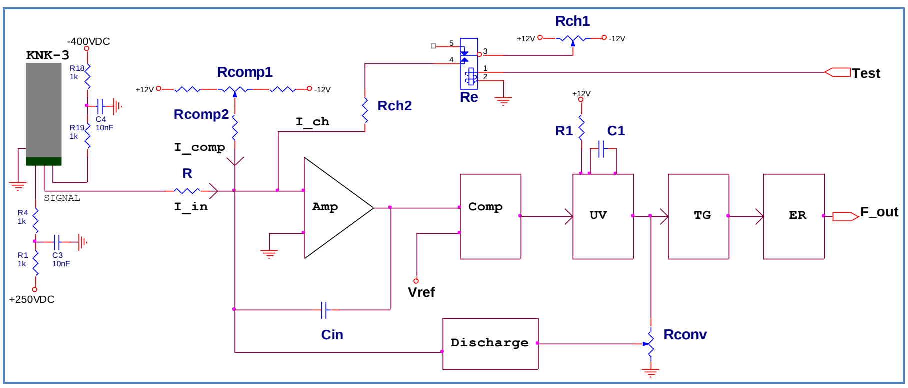


Fig. 7. The block diagram of the current to frequency converter.

2. Testing and results

In the laboratory:

The CFC block covers the range from 3 nA to 1 mA of the input current. The testing diagram is shown in Fig. 8 and the dependence of the output pulse frequency on the input current value is shown in Fig. 9.

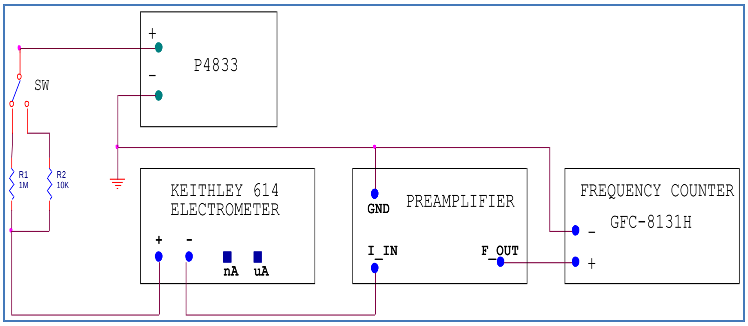


Fig. 8. The testing diagram for the CFC block.

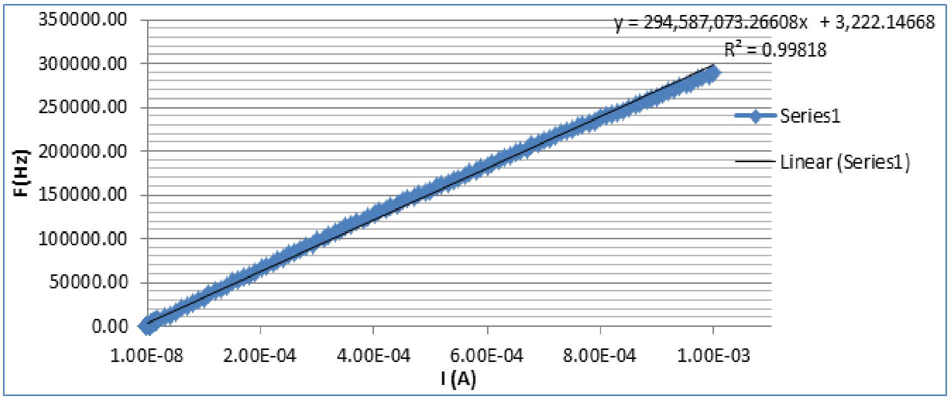
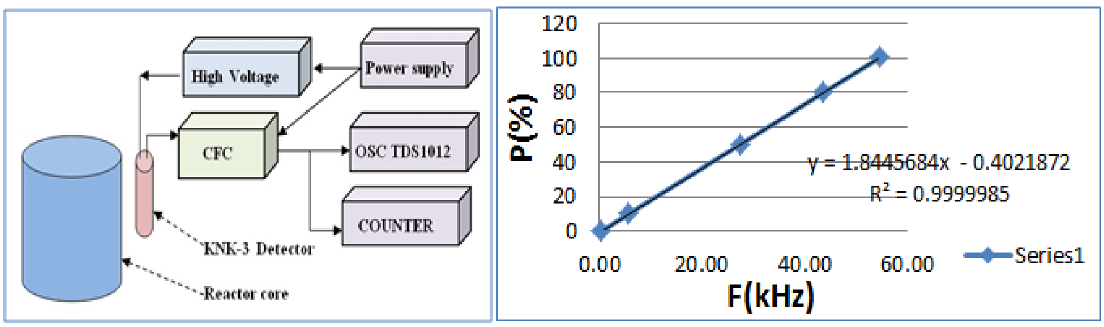


Fig. 9. The relation between input current and output pulse frequency of the CFC.

At the reactor:

The maximum output current from the KNK-3 detector at power of 500 kW is only about 400µA, so that the CFC block was calibrated for working in the range from 1 nA to 400 µA of the input current. The CFC was connected to the KNK-3 detector of the power range No.1 and tested at some reactor power levels from 10^{-1} to 10^{2}% P_n (Fig. 10.a). Fig. 10.b shows the relation between the power levels and the output frequencies of the CFC block.



(a) (b)

Fig. 10. Testing CFC block at the Dalat NRR.

3. Main specifications of the CFC block

- Range of input current: 3 nA ÷ 1 mA;
- Range of output frequency: 0 Hz ÷ 350 kHz;
- Linearity in full range: 99%;
- Pulse amplitude: +12V;
- Power supply: ±12 VDC/200mA and +5 VDC/300mA.

D. Power Supply block [1]

The Power Supply block is intended for the organization of electric supply for neutron detectors, CFC and Pulse Preamplifier blocks. It consists of a high voltage power supply unit and a low voltage power supply unit. The high voltage power supply unit used THV 12-500P/N components and the low power supply unit used TEN15-2412 components of TRACO POWER Company. Its main specifications are shown in the Table II.

Table II. Main specifications of the power supply block.

High voltage power supply	Low voltage power supply
Input voltage: 10.8 VDC to 13.2 VDC	Input voltage: 18 ÷ 36 VDC
Positive high voltage adjustment range from 0 to +500 VDC	Output voltage ± 12VDC and output current max: 1250 mA
Negative high voltage adjustment range from 0 to -500 VDC	Output voltage +5 VDC and output current max: 1000mA
Max Current: 6mA	Ripple and noise: < ±30mVpk
Ripple and noise: 30 mVPk-Pk	
Short circuit and over voltage protection	

The power supply block was tested in different conditions of temperature and humidity with all its main specifications as shown in Fig. 11. The testing results were presented in the final report of the research project [1].

Fig. 11. Testing of the power supply block.

III. CONCLUSION

A new preamplifier device (Fig. 12) which intended for research reactor I&C system, has been designed and constructed. The testing results have shown that almost its design specifications are equivalent or better in comparison with the same function blocks of the DNRR's control system which was made by the former Soviet Union and can be used for the experimental and training purposes. In order to fully test the Pulse Preamplifier block at the operation condition of the reactor, a special permit and significant time resources were required. In this regard, a device that simulates the FC signals in different modes is necessary to design and fabricate [6]. FC signal simulator allows us to generate a model signal of FC in a wide range of pulse rates, i.e. allows modeling different modes of FC.

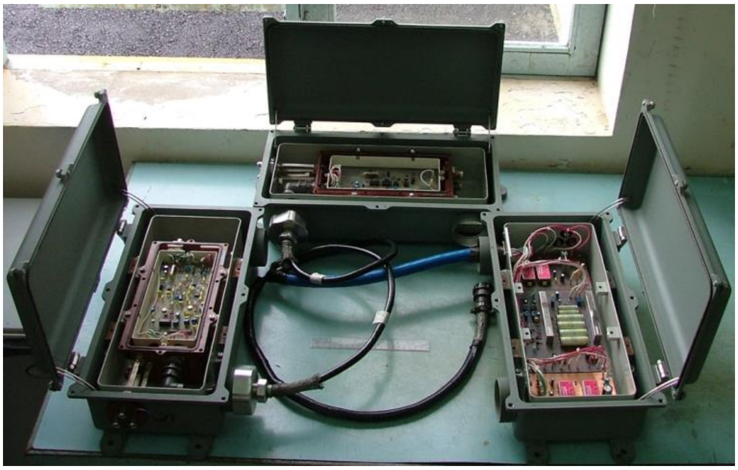


Fig. 12. The designed preamplifier device.

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