OPERATIONAL AMPLIFIER AND FUNCTION GENERATOR FOR USE IN AUTOMATED "MÖSSBAUER EXPERIMENTS"

By

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Introduction

Based on the studies of Mössbauer et al. the investigation of γ resonance fluorescence has become ever more extensive in recent years, leading to the availability of a lot of valuable information in solid state physics, nuclear physics and chemistry. As is known, the measuring process comprises the steps of passing a slightly modulated monoenergetic γ ray through an absorbent and determining the intensity of the transmitted radiation in terms of energy modulation. An absorption spectrum is thus obtained wherein the information is represented by the minimum values of intensity, half-width value of decrease etc. Manual performance of the measurement is very lengthy and tiring and to obtain accuracy better than a given one, very complicated systems must be used. The automation of the process decreases the measuring time and enables the operator to obtain a better accuracy by means of certain given electronic equipments.

Automatic systems employing multichannel equipments

Multichannel systems (e.g. multichannel pulse-height analyzers or multiscalers) are the most advantageous for the measurement described above. The following is to introduce to the electronic system connected, to a

a) *multiscaler* (Fig. 1). The coil A of transducer 7 is driven by the power amplifier 1. Amplifier 1 is excited by the difference signal of difference amplifier 2, the signal obtained by subtracting the velocity signal of coil B from a wave derived from the function generator 3. If the function generator supplies a signal increasing and decreasing periodically and linearly with the time, i.e. a triangular signal, the velocity of the transducer i.e. that of the γ source will increase and decrease linearly with the time and modulated γ energies will be obtained. The γ particles transmitted through the absorbent are detected by the scintillator 8. After the amplification by 4 the pulses are sorted by the difference discriminator 5 and the selected pulses are taken to the input of the multiscaler 6. The operation of the function generator is synchronized by unit 9 to the cycles of the multiscaler, thus each signal which corresponds to a γ energy value is passed into the same channel and when the measurement is finished can either be displayed on an oscilloscope or printed.

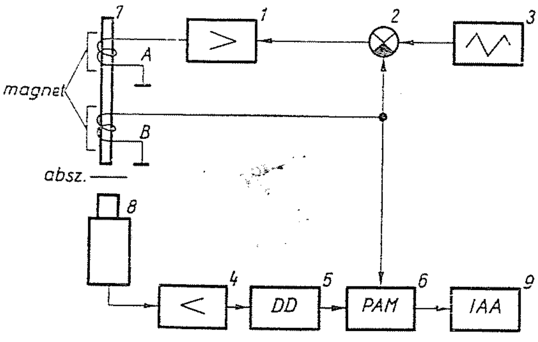

Fig. 1

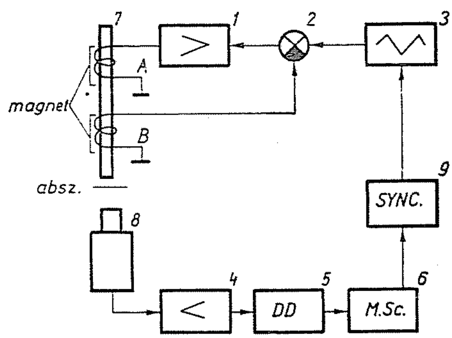

Fig. 2

b) *multichannel pulse-height analyzer* (Fig. 2). Employing a multichannel pulse-height analyzer the generator operates as a free-running oscillator while the transducer is moved in the same way as before.

The standard output signal of the difference discriminator is passed on to the multichannel pulse-height analyzer 9 through a pulse-height modulator (6) which modulates the amplitude of standard pulses corresponding to the actual velocity of the γ source, therefore, the amplitude of the modulator outpout signals will be proportional to the energy of the γ particles. The analyzer sorts these pulses and writes them into the channels, after the read-out the absorption spectrum is obtained.

Development of the electronic equipments used in automated Mössbauer experiments was initiated by the requirements of the Mössbauer-laboratory of the KFKI (Central Research Institute for Physics). The individual units had to correspond to the rack-standard used in our Institute.

Both automated systems comprise two devices, namely, the difference amplifier 2 and function generator 3, which devices primarily affect the accuracy of the spectrum obtained, therefore they must be very carefully constructed.

The following sections are to describe these two devices in detail.

Operational amplifier

The operational amplifier employed in the automatic system is required

1. to have inputs suitable for the production of differences with low base-level drift,
2. to be of constant frequency-transmission and undelayed phase-characteristic over the range from 0 Hz to at least 10 KHz,
3. to be of high stability and to be independent of supply voltage fluctuations,
4. to have high linearity.

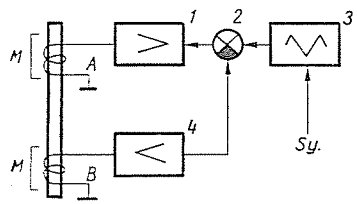

Fig. 3

One of the methods which advantageously satisfies the above requirements is the application of a chopper. This converts the signal to an A. C. signal and this is amplified by and A. C. amplifier possessing a high degree of negative feedback. Under the given conditions it is not easy to choose the adequate chopper frequency and to remove the chopper signal from the output of the device. In order to eliminate this problem a direct coupled amplifier was designed. Since the coil B of the transducer generates a signal of low amplitude (cca. 200 mV) at the lower velocities of the source, the amplifier has a construction providing amplification of high linearity and a low base-level drift and also complying with the requirements of the difference amplifier 2 (Fig 3).

The amplifier is shown in Fig 4. The input difference amplifier (1) produces a difference signal by subtracting the two signals taken from the inputs. The difference signal is amplified by the actual amplifier (2) and passed on to the power stage (3) followed by output attenuator (4). Switching over the switch K the two-channel difference amplifier operates as a single-channel linear amplifier with low output impedance, whose gain is adjustable by the output attenuator.

The input stage is required to have low base-level drift and to be independent of the supply voltage fluctuations. A well-known method for satisfying these requirements is the application of double-triodes mounted in a common

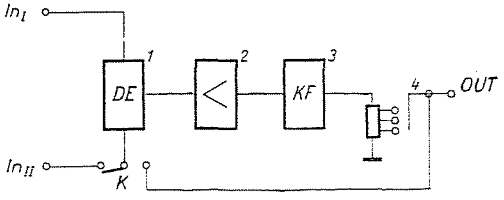

Fig. 4

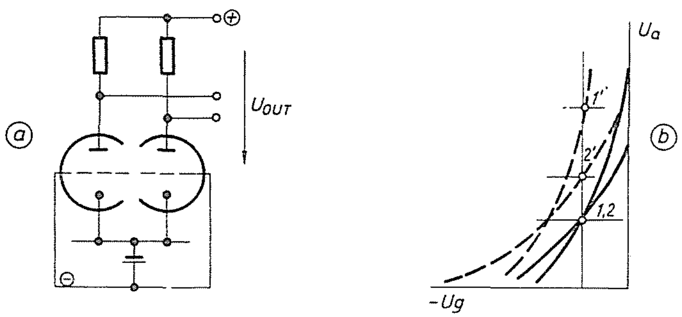

Fig. 5

bulb. In such a design the long-term instabilities of the input stage and consequently the whole system are determined by the symmetry of the tube characteristics and the stability of cathode-material.

Asymmetry of the tubes results primarily in that the input stage is dependent of the power-supplies. Investigating the simple bridge circuit shown in Fig. 5a one can see that any fluctuation of the anode voltage or the filament power results in the shift of U_{ki}, this is also shown in Fig. 5b representing the characteristics. The drift is significant, however, it can be decreased by stabilizing the anode current of the stage with a current stabilizer constructed from a triode placed into the common cathode circuit (Fig. 6). There is a high resistor in the cathode circuit of the triode mentioned before, introducing a high degree of negative feedback and leading to I remaining sufficiently stable despite the fluctuation of either U_k or U_T. (Making use of a tube with a gain of $\mu = 100$, $\frac{\Delta I}{U_k} = 10^{-4}$ and $\frac{\Delta I}{U_T} = 10^{-2}$ generally achieved.) Replacing the triode by a pentode ($\Delta I/\Delta U_T$ better than 10^{-4}) it was observed that the stability decreased, $\Delta I/\Delta U_T$ was about 10^{-1}, unless separate, stabilized screen-grid voltage supply was used.

For common and stabilized cathode current the output voltage of the stage is determined by the current distribution between the two half-tubes, the distribution depending on the fluctuations of anode voltage because of the asymmetry of characteristics and differences of cathode- and grid-voltages. Fluctuations of the anode voltage can be eliminated by stabilization and boot-

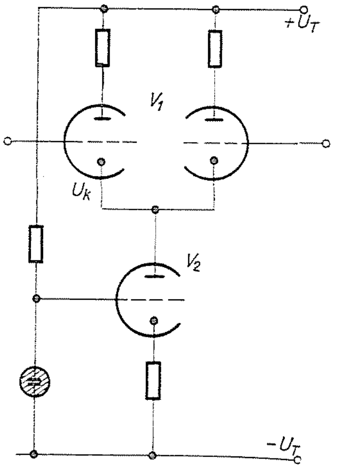

Fig. 6

strap operation in accordance with the input signal, this method also improves the linearity, especially for higher amplitudes.

The changes in the contact-potential between the grid-cathodes depend on the sameness of cathode-materials, these changes cannot be eliminated since the ratio between the metallic-barium and oxide surfaces of the cathodes in the two half-tubes is different. Considering the differences existing in the ratios of the metallic barium and oxide surface of the cathodes, even for the same chemical composition, it can be stated that the above changes depend not only on the cathode current but also on the fluctuations of filament voltages.

Several types of double triodes were tested in accordance with the point of view discussed above and the Siemens E 283 CC was found to be the best. For filament voltage of 0.1% fluctuation and 1 mA anode current the change of contact-potential, measured 1 hour after switching on, at an interval of 24 hrs, was less than $\pm$ 1 mV for each tube. Even those tubes could be selected which had a drift of only $\pm 200\ \mu$V/24 hrs. Using these at an input stage an appropriate amplifier could be built, which amplified the minimum 200 mV input-level with a base-level drift of ± 0.2 per cent.

After the input stage the signal is amplified by push-pull amplifiers, thus eliminating the effects of contact-potential fluctuations of the second tube on the amplification and utilizing the total amplification by using no dividers. The second stage is followed by an output stage and an attenuator, the latter being adjustable either step by step or continuously by a 10-turn helical potentiometer.

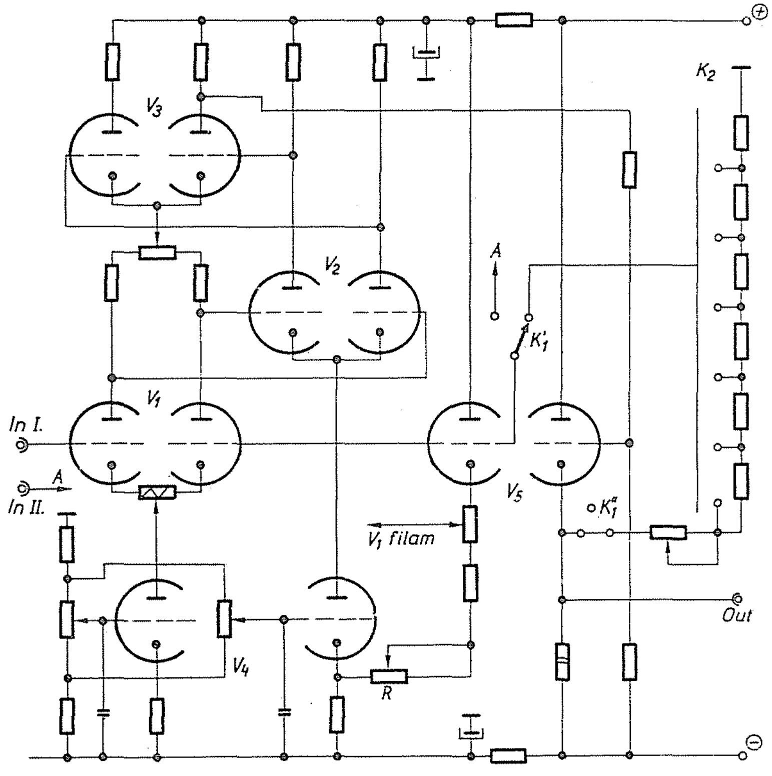

Fig. 7

The entire circuit diagram is shown in Fig. 7. The common cathode-current of V_1 in the input stage is stabilized by the triode V_{4a}. (Since the power-supply is stabilized, the grid circuit of V_{4a} has no separate voltage-regulator tube.)

The distribution of constant cathode currents between the two half-tubes is in accordance with the grid-voltages of the input stage. The amplified control voltage is taken in a push-pull circuit to the grids of V_2, whose common cathode current is controlled in accordance with the input voltage, thus, after setting by the resistor R, the anode voltage of V_2 and cathode voltage, of V_3 increase together with the increasing input voltage. A boot-strapping of the anode voltage of V_1 was thus provided. The amplified output voltage is passed to the output by a cathode follower. One of the inputs of the input stage can be connected to the output attenuator by means of switch K, now the system operates as a single-channel amplifier of high linearity.

V_1 is heated by a D. C. voltage with a stability of $\pm 0.1\%$, the potential of the filament electrode is charged up to the value corresponding to the cathode of V_1 by the cathode follower V_{5a}.

Specifications of the amplifier

U_{be} (input voltage)	max ± 10 V
U_{ki} (output voltage)	max ± 10 V
I_{ki} (output current)	max $\pm$ 4 mA
Gain	min 2.10^4 (without feedback)
Output impedance	1 kOhm (without feedback)
Gain*	1—50
Output impedance*	0.1 mOhm
Linearity*	10^{-4}
Base-level drift	± 0.5 mV/24hr for the input

*with feedback

Function generator

The output signal (Fig. 8) of the function generator is required to satisfy the conditions listed below.

The amplitude of the signal is not critical, but its stability should be better than 1%, the positive and negative values should be equal with the same accuracy.

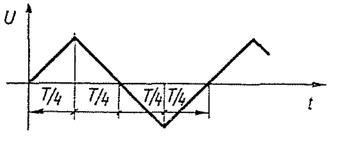

Fig. 8

The frequency of the signal should be adjustable over a range from 0.5 to 25 Hz, the duration of the quarter periods should by equal with an accuracy of at least 1 per cent.

The linearity of the signal must be better than 1 per cent. The generator operates with a capacitor whose potential varies linearly with the time under the action of a constant charge-discharge current, derived from two current generators connected in series. The first gives twice the current delivered by the second circuit. For simultaneous operation of the two generators the charging current of the capacitor.

$$I_k = -2I_1 + I_2 = -I$$

During a given interval the capacitor discharges to

$$-U_{max} = \frac{I_k \cdot T/4}{C}$$

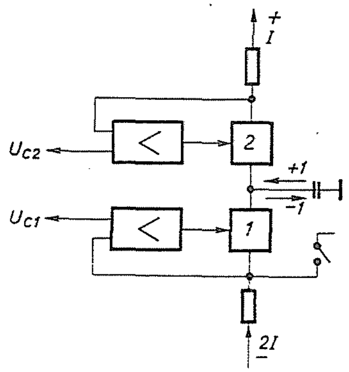

Fig. 9

at this time generator 1 is switched off and the current is delivered only by 2. Now

$$I_T = -I.$$

Hence

$$+U_{max} = \frac{I_T \cdot T/2}{C} - U_{max}$$

and generator 1 is switched on again.

Keeping the signal-height constant the output frequency depends on not only I but also C. The half-periods are equal if

$$I_2 = 2I_1.$$

The circuit diagram of the function generator is shown in Fig. 10. Current generator 1 consists of amplifiers (V_2; V_3), having difference stage V_1. V_{3b} is controlled by signals from the previous stages so that the voltage drop on resistor R_1 should be equal to that present by potentiometer P_1.

If the linearity is to be 10^{-4} the value of the charging current must not decrease more than 0.01 per cent, even in case of maximum capacitor voltage.

Let $U_{C\,\max}$ be ± 10 V and the voltage drop on R_1 150 V for I charging current. The control voltage due to current changes

$$U_v = 10^{-4} \cdot 150\,\mathrm{V} = 15\,\mathrm{mV}$$

causing 10 V change in the grid voltage of V_{3a}.

Thus the gain of intermediate stages must be at least

$$A_I = \frac{U_{g3b}}{U_v} = \frac{10}{15 \cdot 10^{-3}} = 666$$

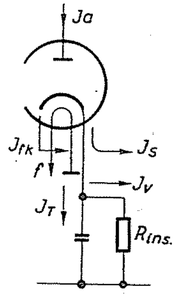

Fig. 10

if the increase of the grid potential caused by the penetration coefficient (D) of V_{3b} is neglected.

One can see that the control voltage (15 · mV) corresponding to the linearity required exceeds the base level drift of the first difference stage (5 mV), thus the filament of the first stage need not be stabilized. Current leaks must be considered, since the current generator stabilizes the anode current of V_{3b}, whereas the charging current is the difference between stabilized current and current leaks.

Considering the cathode circuit (Fig. 11) the actual charging current

$$I_T = I_a - I_{fk} - I_s - I_v - I_g = I_a - I_1$$

where $I_{fk} = I_{fk}(U_C)$; I_{fk} is the current leakage from the insulation of cathode-filament, $I_s = I_s(U_C)$; I_s is the current from the tube socket, $I_V = I_V(U_C)$; I_V is the current from the insulation of capacitor and wiring, and I_g is the current from the grids of tubes connected to the cathode.

I_1 varies essentially (approximately) linearly with the potential of capacitor plates. For charging current $I_T = 1$ mA the permissible current leakage

$$I_1 = 10^{-4}\,\mathrm{mA}\,.$$

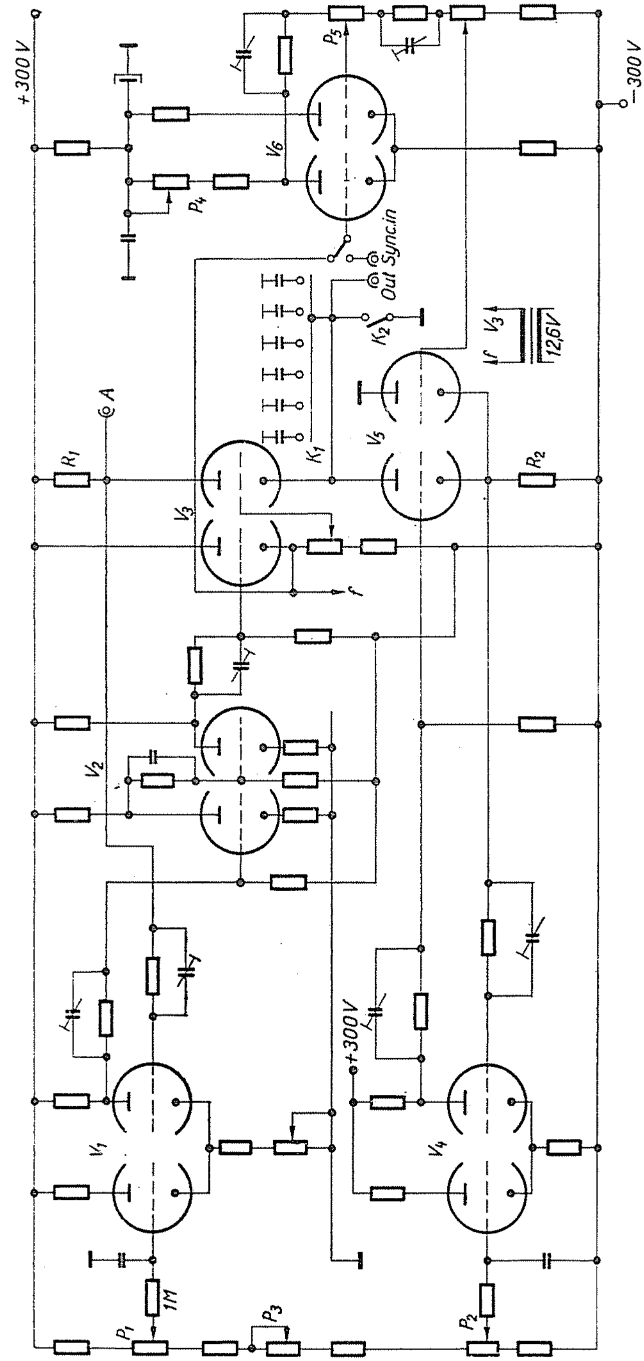
+300 V
−300 V
V1
V2
V3
V4
V5
V6
P1
P2
P3
P4
P5
R1
R2
A
K1
K2
Out
Sync.in
f
1M
12,6V
+300 V

Fig. 11

The grid current of Siemens E 283 CC tube employed in the difference stage was observed to be about 10 nA for grid-bias voltage $U_g = -1$ V, for low amplitudes this value can be taken as constant. (Considering the leakages (losses) the effect of the grids of tubes connected to the anode is the same as that of those connected to the cathode.) The grid current of the E 81 CC used for charging tube is about 20 nA. Substracting this value from I_1 we have the current leakage of insulations

$$I_{\text{ins}} < 70\,\text{nA}$$

determining the minimum resistance of cathode insulation

$$R_{\text{ins}} = \frac{10\,\text{V}}{7 \cdot 10^{-8}\,\text{A}} \cong 150\,\text{Mohm}.$$

For Remix KCPM capacitors with 10—50 μF capacitance tested 600 V the resistance of insulation reaches the values calculated above. The high resistance can also be provided by using ceramic sockets, glass insulated Etronax B chassis for the printed circuit and polyethylene-screened cables at the outputs. The insulation-resistance between the cathode and filament in V_{3b} is not greater than 200 MOhm, therefore a well-insulated special filament transformer was used and the potential of the filament was equalled to the actual cathode potential of V_{3b} by a cathode follower. The cathode of the charging tube (V_{5b}) of current generator 2 has a constant potential, here it is easier to meet the requirements i.e. to provide the $U_{C\,\max}$ required. Potential changes on the anode produce in the cathode circuit only

$$\Delta U_k = \frac{U_{C\max}}{u_{V_{5a}}} = \frac{10\,\text{V}}{100} = 0.1\,\text{V}$$

where μ_v is the gain of the charging-tube. Such a grid-voltage change is sufficient to keep the cathode voltage and consequently the cathode current constant. Permitting a 15 mV cathode voltage change

$$A_2 > 6.6$$

in the amplifier stage of current generator 2 is enough.

The current yield of this generator is 2 mA, this current is used to charge and discharge the capacitor. The current of this generator should be switched off when the anode current of V_{5b} half-tube is switched on, since the circuit is to stabilize the cathode voltage, and to introduce the anode current of V_{5b} by decreasing, possibly (cut-off) the current of V_{5a}. The grid of V_{5b} is conctrolled by Triggering a Schmitt-circuit of high hysteresis. The Schmitt-circuit can be controlled either externally or directly by the capacitor voltage, in the latter case the system operates in a self-excited manner.

Since a common divider is used to introduce the reference voltages of current generators 1 and 2, I_1 and I_2 are determined only by the ratio between resistors in the divider, while potentiometers P_1 and P_2 are used to set the ratio i.e. the equality of quarter-periodes of the output signal.

Varying the resistor P_3, the current of the divider consequently the frequency of the generators is finally adjusted. In the case of equality between the amplitudes of output, signals P_3 tunes the frequency. In the case of free-running operation P_4 and P_5 set the signal-height and base level, respectively. The output is shortcircuited by K_2, this makes not only the reset easier but also the setting of characteristical values of the current generators. In a free-running mode the base level of the output signal depends on the stability of triggering levels in the Schmitt-circuit, and generally it is less than ± 50 mV. In the synchronized mode of operation the intervals between the synchronizing signals must be symmetrical and the condition $I_2 = 2\ I_1$ must be satified, otherwise a slow shift of base-level will appear. In given systems, using adequate detectors the back-control is possible, if a current is taken to input A or a resistor is connected between A and the ground when the base level shift is positively orientated. Main specifications of the signal-generator

Linearity	$0.9 \cdot 10^{-4}$
Signal-height	± 10 V
Frequency	0.5; 1; 2.5; 5; 10; 25 Hz $\pm 20\%$
Maximum output current	± 50 nA
Base-level stability	± 30 mV/8 hours

Owing to the low output current of the function generator an afore described single-channel operational amplifier is connected to the output, which amplifies the signal with a required linearity sufficient with a 10^{-3} Ohm output impedance.

Summary

The paper describes automated Mössbauer-spectrometer systems operating with multiscaler and multichannel pulse-height analyzer. The spectrometer is built into a sub-rack system.

A detailed discussion is given of two essential parts of the system: the DC operational amplifier and the function generator. Using there the linearity of the spectrum and the stability of the base level drift are better than 10^{-3}.

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