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A CURRENT SOURCE WITH LINEARLY CHANGED OUTPUT FOR NMR APPLICATIONS[1]

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The current source is designed for NMR application in the low temperature experiments. The current is operating in the range of 0–6.5 A with a setting accuracy of 100μA at a maximum output voltage of 7V. The current can be swept linearly in time with various rates and its value is measured with resolution of $\sim 25\mu$ A. This value also corresponds to the time stability of the output current in standby mode. Other characteristics of the source are also presented.

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1 Introduction

The nuclear magnetic resonance (NMR) is very powerful technique used to the study of various magnetic behaviors of the condensed matters. Any application of the NMR technique assumes a presence of magnetic field usually with homogeneity and stability of order of 10^{-4} or better. While homogeneity of the fields depends on the design and manufacture of a superconducting or normal solenoid (magnet) generating magnetic field, the field stability and a possibility of the field changes depend on the properties of a current source which supplies this solenoid. The solenoid represents an inductive load for the current source and therefore any change of the output current has to be done in a continuous way. A lack of commercial current sources with special characteristics forces the experimenters to design and built them themselves [1]. An aim of this article is a description of a novel programmable current source. The novelty of the source design is based on a long term experience [2, 3] and consists in how to solve problems with step like response of the source output current due to a D/A converter which usually controls the source output current. Here we have exploited the properties of an analog integrator being controlled by this D/A converter as a reference voltage source [4]. This connection allows: (i) a smooth change of the integrator output voltage i.e. a smooth sweep of the output current without steps provided by D/A converter, (ii) the possibility to adjust the integrator output voltage i.e. the source output current with the resolution of the D/A converter used, and finally (iii) when the integrator output voltage finishes (i.e. the source output current) its sweep then it is stabilized by an active feedback which provides its stability as that of the D/A converter i.e. with the stability of order of 4.10^{-5} in our case.

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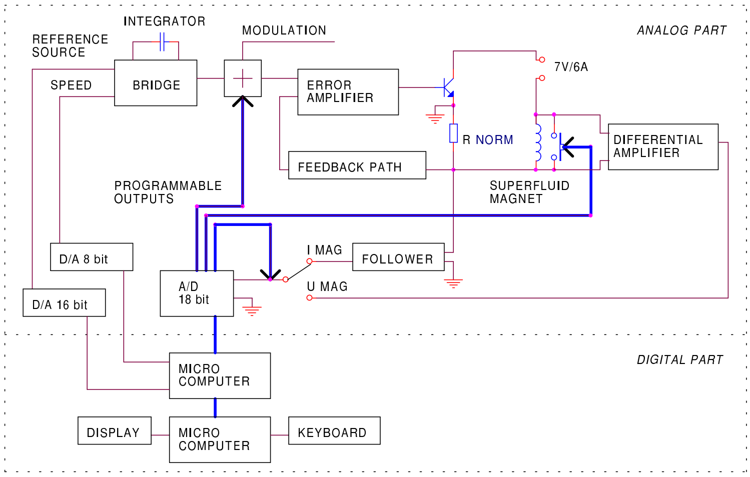

Fig. 1. A block scheme of the current source.

2 Current Source

The block scheme of the current source is presented in Fig.1. Two parts – a digital and an analog one connected together via opto-couplers are highlighted. The digital part consists of two independent processors communicating each other via their serial ports. The first processor controls a keyboard and display while the second processor drives the analog part according to the data send by the first processor. Individual input entries from the keyboard are shown on the display for the user easier control before they are stored. The input parameters of the source are, for example, a current limitation, an output voltage limitation, a required current, a sweep rate, etc. Current status of all parameters entered can be displayed at any time. During operation both processors communicate in real time and the data transfer between them consist of the actual permanently measured values of the output current and voltage which are sent to 'the display' processor to be shown if necessary while the parameters entered from the keyboard travel in the opposite way.

The source is designed for the maximum output current of 6.5 A. The output current is stabilized in a usual way – a voltage drop on a reference (or normal) resistor generated by the current flow is compared with the value of a reference voltage source using an error amplifier. The error amplifier drives a conductance of the power transistors and thus controls the magnitude of the current flow in negative feedback. As the reference voltage source serves a D/A converter. The selection of the D/A converter determines not only the minimal step of the output current adjustment but also its time stability because D/A converters having higher resolution usually have better stability. As result we have used a 16 bit D/A converter which gives minimal step of the output current setting to be $\sim 100\ \mu$A. To solve the problem with steps provided by the D/A converter a new connection has been developed with a diode bridge which works as a switch controlled by a comparator. The D/A converter output is linked to a non-inverting input of the comparator. Its output is connected to one node of the diode bridge. The opposite node of the bridge is bonded to an integrator. The rest two nodes of the diode bridge are connected to two identical current sources, however, one is positive and the second one is negative. These current sources alternately feed the arms of the bridge as long as the output voltage on the integrating element is equal to the output voltage of D/A converter. A principle of operation is simple: when the D/A converter is set to any value, one of these current sources, via the diode bridge, starts to charge/discharge the integrator until the integrator output value is reached the same as the D/A converter's is. Then the comparator changes the state of the diode bridge and the second source starts to discharge/charge the integrator. The integrator output voltage alters once more and the comparator changes the state of the bridge again connecting the opposite source. As result, a dynamical equilibrium state is established and the integrator output voltage, U_I, oscillates around the reference voltage value with amplitude $\delta U = U_I/A$, where A is the gain of the feedback loop typically of order of 10^6.

The rate of sweep depends on the value of the integrator capacitor and on a magnitude of the charge/discharge current. The value of the charge/discharge current is controlled using an 8-bit D/A converter allowing to set the speed of the output current sweep from the actual state to the target value at 256 different values. In reality it represents a total time of the sweep from few tens of seconds up to tens of hours for full range sweep of the output current.

The magnitudes of the output current and voltage are continuously measured in time. The current is monitored via follower, while the output voltage is amplified by a differential amplifier. Both values are alternately measured using a commercially available 18-bit A/D converter. The A/D converter has four programmable outputs from which three are exploited. One is used to connect a modulation input, one serves as a switch to select between the inputs of the A/D converter (output current or output voltage) and next one drives a relay which provides for a short circuit over the output terminals of the current source. The short circuit of the current output terminals is the default state after the current source is switched on. Relatively high resolution A/D-converter offers good compromise between the rate of conversion and the resolution. Thus the output current is measured with sensitivity of order of 0.0004% of full scale range what, in case of the source presented, corresponds to $\sim 25\mu A$.

3 Discussion

Basic characteristics of the current source i.e. the time sweep of the current and then its time stability are presented in Fig. 2. The current was measured independently as a voltage drop on the reference resistor of nominal value of 1 Ohm using the Keithley high resolution nanovoltmeter. As one can see from Fig. 2 a long time stability (10 hours) of the output current is better than 4.10^{-5} what satisfies the requirements for NMR applications. Using the Larmor expression $\omega = \gamma B(I, z)$ with γ being the gyromagnetic ratio and assuming the simplest case that the magnetic field is only a function of the current I and coordinate z, then the frequency change can be expressed as:

$$d\omega = \gamma \left(\frac{\partial B}{\partial I} dI + \frac{\partial B}{\partial z} dz \right). \qquad (1)$$

First term describes changes due to current instability while the second one is the result of the spatial inhomogeneity. Thus, the current instability of order of 4.10^{-5} corresponds to the change

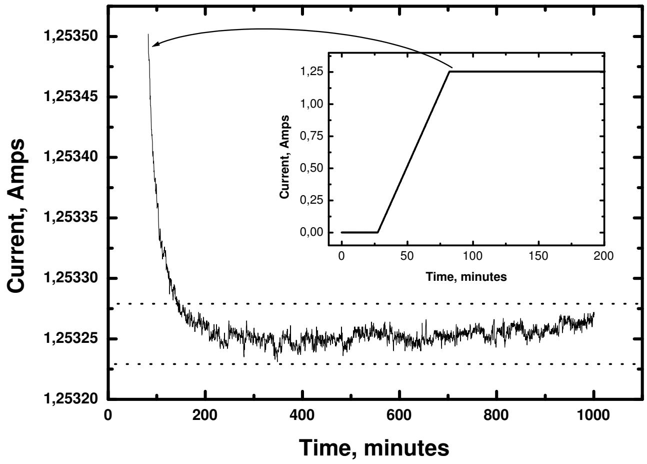

Fig. 2. A long time stability of the output current including a relaxation of the current started immediately after the end of the current sweep to 1.253 Amps. The dashed lines delimit the window of 50 μA changes of the current. Insert shows a linear increase of the current in time and the arrow points on the detail of the current relaxation.

in the frequency of 25 Hz at the Larmor resonance frequency of 500 kHz (in case of NMR on superfluid ^{3}He this frequency corresponds to the field of $\sim$ 15 mT). On the other hand if one assumes the field gradient (or spatial field inhomogeneity) to be $\nabla B = 1\mu T/cm$ and a typical length of the experimental cell in experiments with 3He of $\Delta l = 1cm$, corresponding width of the resonance line is $\delta f = \gamma \nabla B \Delta l \sim 32Hz$ with $\gamma = 32.4MHz/T$ for ^{3}He. In such a way the properties of a magnetic field system for NMR will rather be dependent on the design and quality of solenoid (magnet) manufacture than on the characteristics of the current source presented. The results obtained also confirm the advantages of the new connection which exploits the properties of the analog integrator being controlled by the D/A converter working as the reference voltage source.

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