

DESIGN OF MEASURING AMPLIFIERS FOR MAGNETIC MEASUREMENT

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Abstract: The purpose of this paper is a design of a measuring preamplifier for a fluxmeter which was designed in Department of Theoretical and Experimental Electrical Engineering which is used for hysteresis loops on ferromagnetic materials measurements. Having respect to measure coils characteristics and processed voltage levels with ranges in nV and μV , there was necessary to investigate measure principles of such low voltage. And then choose an appropriate operational amplifier. Mainly with minimum input residual voltage and offset temperature dependency. Also was necessary to propose effective zero compensation and eliminate thermoelectric influence in the whole designed device. There was applied noise optimization of selected operational amplifier in PSpice software. And in the last part of the paper will be show results of noise measurement on the amplifier. The given results will be evaluated together with possibilities of application for a measurement purposes in labs.

Keywords: Fluxmeter, operational amplifier, modulation amplifier, automatic zero operational amplifier, input noise measurement

1 INTRODUCTION

One of the most important components for measuring hysteresis curves of ferromagnetic materials is the electronic Wb-meter, or fluxmeter. It is an integration amplifier that processes the voltage from the measuring coils. These voltages are usually very low, at the nV and μV levels. It is therefore necessary to ensure a very good offset compensation of the voltage offset of the entire measuring instrument. In order to avoid spontaneous voltage drift with time and temperature and to avoid voltage drop on the integrating capacitor, due attention must be paid to the selection of all main components. It is also necessary to minimize thermoelectric voltages at all contacts and soldered connections. The fluxmeter developed at the Brno University of Technology (BUT) in the 1980s based on operational amplifier AS101 is still at a very good level and is widely used; however, it already has several disadvantages, especially the connection of the used operational amplifier (OA) only as an inverting amplifier - resulting in low input resistance, as well as a relatively high temperature dependence and low sensitivity, but these shortcomings can be eliminated. The new monolithic operational amplifiers with automatic zero-compensation, enabling connection even in non-inverting connections, are the ideal building block for realizing the measurement preamplifier for the BUT fluxmeter.

1.1 FLUXMETER

Fluxmeter or Wb-meter is a measuring instrument used for measuring magnetic flux. It is used mainly for measurement of the primary magnetization curve and hysteresis curves of ferromagnetic materials. Due to the relatively high purchase price of this device - tens of thousands of Czech crowns, not every workplace is equipped with this device. It is therefore not a common measuring instrument. In its basic principle, this device is only an integrating amplifier, but since very low

voltages, in the order of nV to μV , are processed during measurements, high demands are placed on fluxmeters, see [1], [2].

2 DESIGN OF MEASURING AMPLIFIER

The aim of the design is to design such a pre-amplifier, which will consist of automatically zero OA, input voltage offset below $1\ \mu\text{V}$ and offset temperature drift less than $0,05\ \mu\text{V} / ^\circ\text{C}$. An essential requirement is also the use of OA's in the non-inverting input circuit due to the impedance separation of the measuring coils.

2.1 BLOCK DESIGN OF THE AMPLIFIER

As shown in Fig. 1, the entire preamplifier will consist of three main blocks. The first part will be the discrete instrumentation amplifier "A". Discrete instrumentation amplifier contains two voltage followers and differential amplifier. It will serve for impedance separation of measuring coils. This will not affect the gain of the input amplifier due to the change in impedance of the measuring coil with frequency. The input also boosts the voltage to reduce noise in other parts of the preamplifier. Letter A in every block and numbers in brackets denotes largeness of amplification.

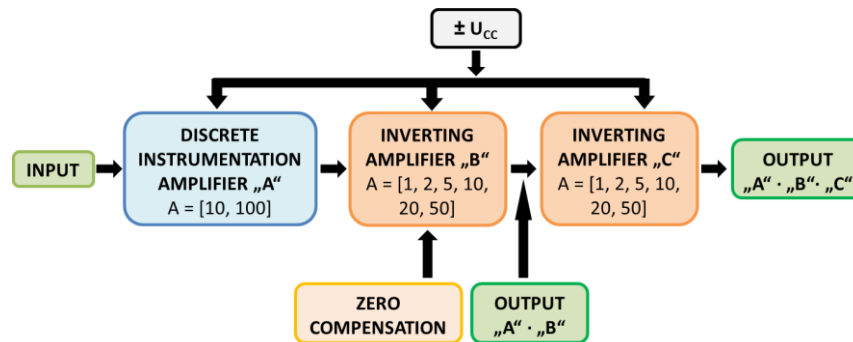


Figure 1: Block diagram of the device

The following two amplifiers "B" and "C" are the main part of the device and amplify the voltage from the instrument input. Another block is a differential amplifier. The use of a differential amplifier is very advantageous here, since this connection allows suppression of common interference. The output voltage is equal to the input voltage difference. The differential gain will be ten. The following two blocks are the same. Both amplifiers are inverting and can be individually adjusted for each amplification step. The voltage offset can be manually reset, because neither automatic zero-compensation is not perfect, and the soldered connections can generate thermoelectric voltages which must also be compensated. If the amplification of the amplifier "B" is sufficient, it is possible to take the amplified signal directly from the output "A" · "B". For very low voltages the resulting gain is given by the amplification product of amplifiers "A", "B" and "C". In order to be able to control the amplifier by means of a control panel, the switching relays are connected via a transistor array to the rear connector of the amplifier. By applying control voltage to a given pin of the connector it is then possible to switch the corresponding relay, see [3]. The whole device is powered by batteries to reduce the effects of line interference.

2.2 AUTOMATIC ZERO-COMPENSATION OA

Automatically zero-compensation amplifiers belong to the group of instrumentation amplifiers intended for measuring purposes. To accurately measure low voltages, it is very important that the input residual voltage is minimized and has little drift - that is, its change.

External components can be used for compensation, or the OA itself is designed to compensate for this voltage itself. Modulating amplifiers are used, whose principle is to convert the input DC voltage using a modulator to AC. This voltage is amplified and then rectified by a demodulator. After

filtering, this voltage is applied to the output. To be synchronous, the modulation amplifier is controlled by an internal oscillator, usually in the order of hundreds of hertz. The amplifier is alternately coupled so that there will be no drift even at high amplification. Fig. 2 shows a simplified wiring of a modulation amplifier, see [4], where MOD denotes a modulator, an AC AMP is AC amplifier, DM demodulator and G generator.

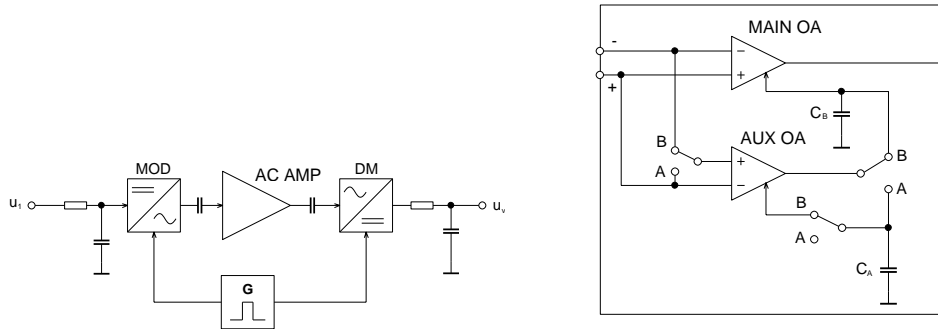


Figure 2: Block diagram of modulation auto-zero operational amplifier (left) and new concept of auto-zero OA (right)

When the modulation amplifier is connected to the operational amplifier itself, the OA is automatically reset. Due to the amplification of the modulation amplifier, the input residual voltage and the voltage drift are reduced in this ratio. This is a very effective method of compensation. Structurally, such an amplifier is integrated in one housing.

The new concepts of auto-zero OA use auxiliary zero OA, several electronic switches and memory capacitors. The whole circuit is controlled by a clock signal with frequency of hundreds of hertz or in newer OA's it is a few kilohertz, see [5] and [6]. This ensures faster and more efficient zeroing. The residual and drift voltage is thus further suppressed, up to several $nV/^\circ C$. Principle block diagram is on Fig. 2. The advantage of this solution is the use of OA in both inverting and non-inverting circuits. This is very advantageous for the preamplifier concept, especially in view of the high input resistance of the non-inverting circuit.

2.3 OPERATIONAL AMPLIFIERS

The main component of the preamplifier is an operational amplifier. Depending on the requirements, it was necessary to select a suitable OA's. The most important criteria were the lowest offset and temperature drift. From a plethora of manufacturers were selected several OA's, which had very good parameters. All selected operational amplifiers have automatic-zero offset compensation, but the disadvantage is the higher noise voltage. However, zero offset was the main requirement for selection. The OA LMP2021 was used in the construction. In Tab. 1 selected types are listed, all parameters are from datasheets, see [7], [8], [9], [10].

	A_0	GBP	S	U_{os}	$\frac{\Delta U_{os}}{\Delta T}$	I_B	R_D	u_N
	[dB]	[MHz]	[V/ μs]	[μV]	[$\mu V/^\circ C$]	[pA]	[M Ω]	[nV/ \sqrt{Hz}]
LMP2021	150	5	2,5	-0,9	0,001	23	-	11
OPA735	130	1,6	1,5	1	0,05	100	-	135
ADA4528	140	3	0,45	0,3	0,002	220	0,225	5,5
LTC2051	140	3	2	0,5	0,01	8	-	-
ISL28134	174	3,5	1,5	-0,2	-0,0005	120	-	8

Table 1: Suitable auto-zero operational amplifiers, where is A_0 open loop gain, GBP Gain-bandwidth product, S slew-rate, U_{os} input offset voltage, $\Delta U_{os}/\Delta T$ offset voltage drift with temperature, I_B input bias current, R_D input resistance in differential mode, u_N voltage noise density

2.4 NOISE MEASURING OF AMPLIFIER

The measured parameter of the amplifier was input noise. The HP 35660A FFT Spectrum Analyzer was used for this measurement, allowing a wide range of measurements in the low-frequency range. The frequency range of the analyzer extends to 100 kHz. Completed measuring amplifier is shown on Fig. 3.



Figure 3: Front panel of the device

The measurement was carried out with a short-circuited amplifier input and its output was connected to one channel of the spectrum analyzer. Averaging 100 values was used. Graphs of the total input noise per unit bandwidth were constructed from the readings for two different gain combinations.

The total input noise voltage, see Fig. 4. It is obvious from the measured dependence that noise is very similar to white noise in its nature, only large frequencies of noise voltage are visible at frequencies around 26 to 30 kHz. This interference causes the automatic amplifier to reset the clock frequency. To suppress this interference, we would have to limit the amplifier's bandwidth to less than 26 kHz or use another type of amplifier that works at higher clock frequencies. This measurement was unique in terms of determining the exact clock frequency of the auto-zero OA, as the manufacturer does not provide this information. The measured input noise voltage in the range of 1 to 26 kHz corresponds to the data of the manufacturer of the operational amplifier and the simulations in the PSpice program. In this frequency range, the amplifier meets the requirements for very low voltage amplification. At very high gains, even on the harmonic signal, the interference from the clocking frequency of OA auto-zeroing is more pronounced. Input voltages lower than approx. 30 nV cannot be measured as they are drowned in noise.

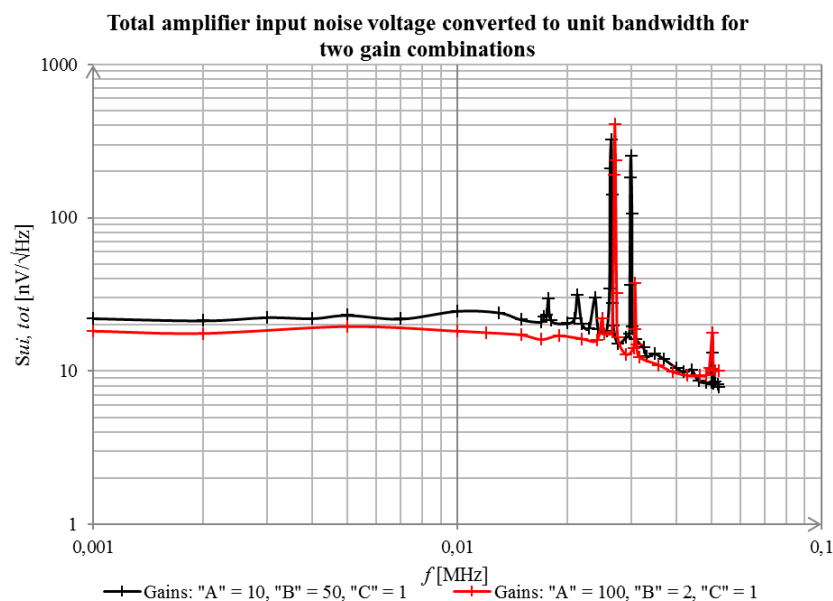


Figure 4: Input noise characteristic, gain description corresponds with marking of amplifiers in block diagram on Fig. 1.

3 CONCLUSION

This paper discusses the design of a low noise fluxmeter preamplifier for measuring hysteresis curves of ferromagnetic materials. Due to the requirements to process very low voltage levels, the concept of a completely analog preamplifier equipped with automatically zeroed operational amplifiers was chosen to compensate for the amplifier voltage offsets as perfectly as possible. The designed device was designed and subjected to measurements. The equipment was also tested in the laboratory when measuring steel samples, where the amplifier worked as expected. I consider it is important to measure the amplifier's own noise, from which it was possible to detect the auto-zero clock frequency, which is not mentioned in the documentation. In terms of usability, the amplifier is universally applicable for amplifying very small signal levels. In the future, it would be interesting to test the amplifier with other types of OA and again make noise measurements and compare them with each other.

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