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IMPROVEMENT OF THE TEMPERATURE AND NOISE PARAMETERS OF THE DIGITALLY CONTROLLED CURRENT SOURCE FOR FLUX-GATE MAGNETOMETERS

The possibilities to improve the temperature and noise parameters of the digitally controlled current source are considered. It is experimentally showed, that one of the best voltage references LTZ1000 exhibits considerable non-linearity of the temperature dependence in the uncontrolled temperature mode. The curvature-compensating circuitry is proposed. The source of the extra noise in the digital-to-analog converter AD5791 is revealed and the appropriate configuration of its inner structure is selected. Application of the obtained results and recommendations will make possible to create flux-gate magnetometers with outstanding temperature and noise parameters.

Keywords: *reference voltage, flux-gate magnetometer, temperature drift, noise.*

Introduction

Flux-gate magnetometers (FGM) are widely used for measuring weak magnetic fields in geophysical and space research, defectoscopy, in medical diagnostics to name a few. However, some areas of application, for example magnetocardiography, require very high resolution of magnetic field measurement. For this, reducing the FGM own noise is very important. Next very important task is improving the temperature stability of both offset voltage and transformation coefficient, especially for space magnetometers and geophysical equipment operating in field conditions. To reach this, the most important is to improve the FGM sensor. New approaches such as the use of ferrodielectric materials [1], special excitation modes [1, 2, 3, 4, 5] can significantly reduce the level of own noise of flux-gate sensor, in particular, down to 0.1 pT/Hz$^{1/2}$ at a frequency of 1 Hz [2] with further decrease to several tens of fT/Hz$^{1/2}$ [1, 6]. Also in the best examples of flux-gate sensors for space research, along with low noise, zero offset is practically independent on temperature: their zero drift is within 1 nT in the temperature range -40 ... + 65 ° C [7, 8].

Using new amorphous magnetic materials [9], that have passed optimal thermomagnetic processing, new flux-gate sensors have been developed in LCISR of NAS and SSA of Ukraine with the level of own noise of 1 and 10 pT/Hz$^{1/2}$ at frequencies of 1 and 0.01 Hz correspondingly, which at the same time have short-term stability of zero offset within 40 pT during few hours and its temperature drift within ± 1 nT in the temperature range of 5 ... 40 °C.

To further improve sensor parameters, it is especially important to provide high temperature stability and small level of fluctuations of the compensation field, which compensates the main component of Earth's magnetic field in the sensor core. The compensation field is created by electric current flowing through compensation winding, which is wound on the frame made from the material with a low temperature coefficient of linear expansion. The paper discusses the possibility of constructing a digitally controlled current source with temperature and noise characteristics consistent with the parameters of the best modern fluxgate sensors.

Study results

For the postulated goal achievement, following noise characteristics of the compensation field were posed: noise level no more than 0.5; 1.5 and 5 pT/Hz$^{1/2}$ at frequencies of 1; 0.1 and 0.01 Hz, respectively, what constitutes 7.1; 22 and 71 10^{-9} /Hz$^{1/2}$ in relative units taking account the compensation range of ± 70000 nT. Instability of compensation field should not exceed 1 nT or $14 \cdot 10^{-6}$ in relative units in the temperature range -40 ... + 65°C. At the condition of a linear dependence of compensation field on the temperature, the thermal drift should be <0,14 pT/Hz$^{1/2}$ 1/°C. The structure of the digitally controlled current source, which consists of a reference voltage source (RVS), digital-to-analog converter (DAC) and current-voltage converter, is analyzed. A detailed review of the characteristics of semiconductor integrated reference voltage source was made and it was found that only very few models have their own noise level, temperature and time drift acceptable to be used in high-class FGM [10]. An indisputable leader within all specified parameters is the reference voltage source LTZ1000 based on subsurface stabilitron for which temperature compensation in the form of base-emitter voltage of the transistor placed on the same chip is used. This reference voltage source also has fairly weak dependence of output voltage on the dose of radiation [11], which may be important for space application. Achieving a record low temperature drift ($0{,}05\cdot10^{-6}$ 1/°C) is due to crystal controlled heating and maintaining its operation temperature in a very narrow range. Taking into account the significant power consumption, this way is not always acceptable in FGM and may be unreasonable due to thermal instability of other units of the RVS. Experimental research of three samples of RVS showed significant nonlinearity of the temperature dependence of the output voltage U_{REF} in the temperature compensation mode without temperature stabilization (Fig. 1), especially at the edges of the temperature range.

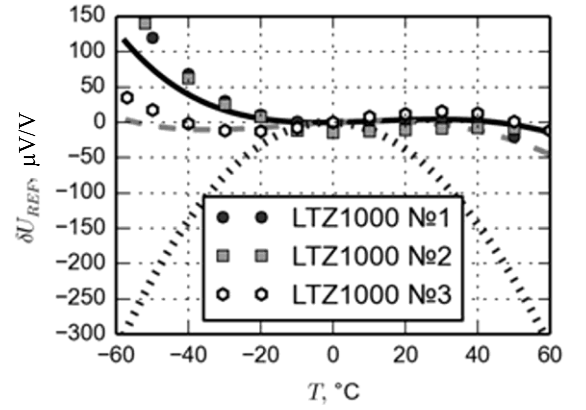
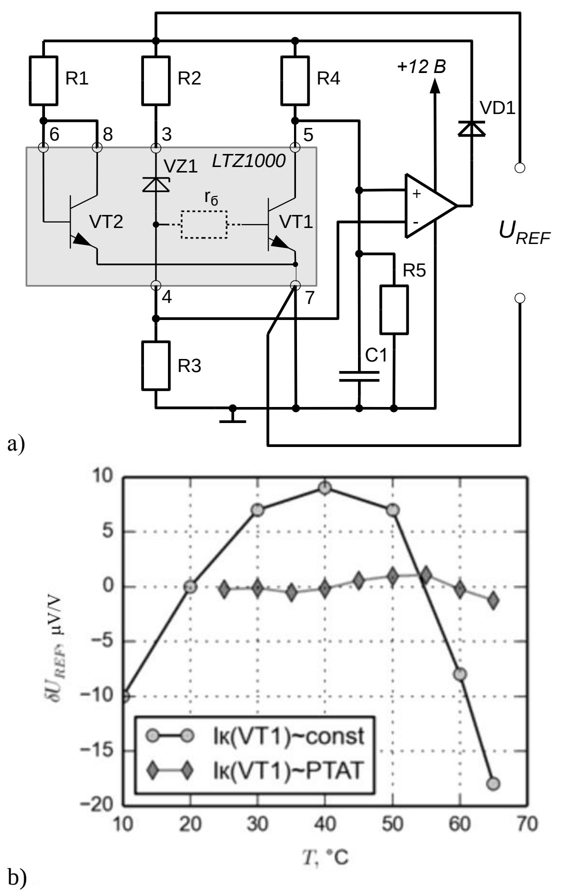


Fig. 1. Temperature dependence of LTZ1000 reference voltage source— simulated results (lines) and experimental data (marks)

According to [12] and computer modeling of the RVS circuit conducted with the help of LTSpiceIV package (Fig. 2, r_b = 0 Ohm, R2 = 18.6 Ohms, R3 = 120 Ohms, R4 = 68,1 kOhms, R5 is absent) expected nonlinearity of the temperature dependence of U_{be} (VT1) and, accordingly, U_{REF} looks like a dotted curve in Fig. 1, what does not match with the measurement results of output voltage of LTZ1000 samples. Much better matching of the model curve (Fig. 1 solid line) with experiment results was obtained by adding the resistor r_b = 15 Ohms (Fig. 2a) to the LTZ1000 circuit given in the technical documentation [13].

Perhaps the U_{REF} voltage increase at low temperatures is due to a decrease of current transfer coefficient of the transistor VT1 and a corresponding increase in base current and voltage drop at r_b, R2 and dynamic resistance VZ1, since a collector current depends slightly on the temperature (≈0,03%/°C). To compensate the effect of the temperature dependence of the base current, and slightly linearize temperature dependence of U_{be} (VT1) is possible if to fix VT1 collector current, which is proportional to absolute temperature of the crystal (called PTAT - proportional to absolute temperature). In the diagram in Fig. 2, it is realized by inserting of the resistor R5. The result of the simulation of the modified circuit (Fig. 2 and r_b = 15 Ohms, R2 = 14.5 Ohms, R3 = 120 Ohms, R4 = 30,1 kOhms, R5 = 6,2 kOhms) is represented by dashed line in Fig. 1. Experimental study of the LTZ1000 sample №3, operating according to the modified circuit, showed a significant decrease in the nonlinearity of the temperature dependence of the output voltage U_{REF} in the temperature range 25 ... 65°C (Fig. 2b). Further it is planned to get temperature characteristics of the modified circuit in a wider range, and specify parameters of the LTZ1000 to obtain more reliable results of computer simulation.



a)

b)

Fig. 2. a) Electric circuit of LTZ1000 connections and b) temperature characteristic of the reference voltage depending on the VT1 transistor operation mode

As a digital-to-analog converter (DAC), one of the best models in the integrated-circuit package - 20 bit DAC AD5791 with temperature drift 0,05 10^{-6}1/°C [14] - was selected. As the description of this chip contains conflicting data regarding the level of its own noise, noise characteristics were examined in two circuit configurations: with bipolar (Fig. 3, Circuit 1) and unipolar (Fig. 3, Circuit 2) reference voltage source.

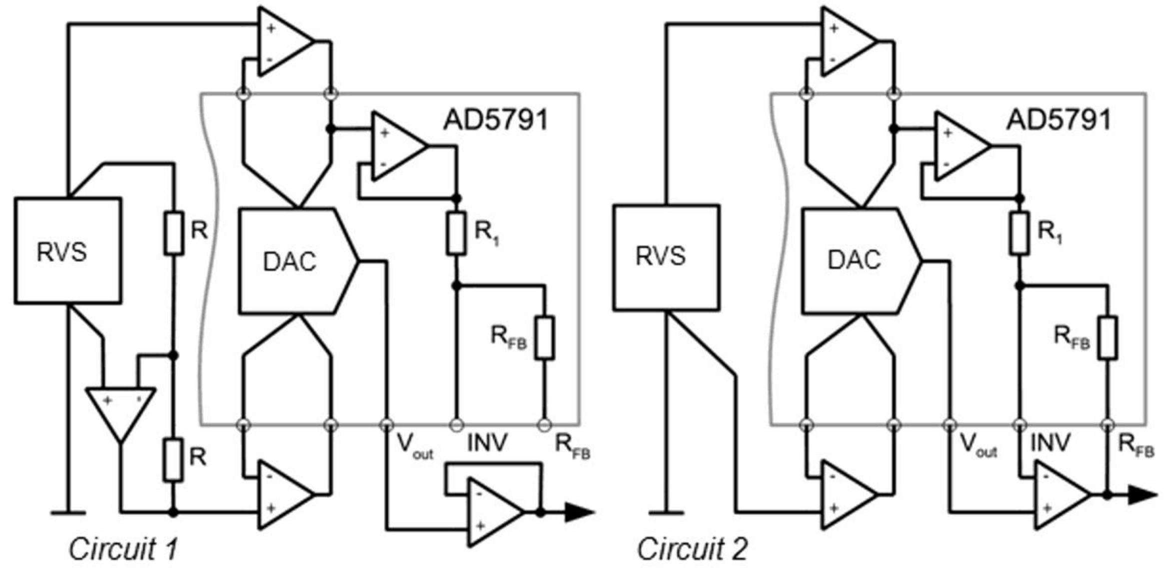


Fig 3. Versions of digital-to-analog converter AD5791 connecting

Table 1. Own noise level of the digitally controlled current source

Frequency, Hz	Relative noise spectral density, 10^{-9}/Hz$^{1/2}$								
	Reference voltage		Output current						Requirements
			“0”		“MIN”		“MAX”		
	circuit 1	circuit 2	circuit 1	circuit 2	circuit 1	circuit 2	circuit 1	circuit 2	
1	**9**	**9**	4	**8**	**9**	**16**	**9**	**9**	□ 7,1
0,1	22	22	7	14	22	**39**	22	22	□ 22
0,01	70	70	15	42	70	**150**	70	70	□ 71

In both cases, the DAC output was connected to the identical voltage-to-current converters with ungrounded load consisting of an operational amplifier OPA2188 [15] with low frequency noise and high stability metal-foil resistors VSMP0805 [16], which have almost linear temperature dependence of the resistance. For each sample, Table 1 shows the relative spectral noise density of the reference voltage as well as output currents at various points in the range: at zero (column "0"), at the minimum ("MIN" column) and at the maximum values ("MAX" column). The values of noise spectral density which exceed given limits, are marked in bold. Overpassing the requirements at a frequency of 1 Hz for border values of current for both cases is connected with increased noise level of RVS. To reduce noise at high frequencies in the future it is planned to install a low-pass filter after the RVS. The noise of power supply assembled according to the circuit 2 is more than the noise of the RVS assembled according to the circuit 1, and exceeds the border values at zero and minimum values of the output current. This is due to the additional noise arising in the resistors R1, RFB when current is flowing through them. So, for better noise characteristics achievement, the AD5791 has to be connected in the version of the bipolar reference voltage source.

Conclusion

The paper discusses the possibility to improve temperature and noise characteristics of digitally controlled current source. It was shown experimentally that the output signal of one of the best sources of reference voltage LTZ1000 has considerable non-linear temperature dependence when used without temperature stabilization. The method of linearization of the temperature characteristic using schematic design is proposed. The source of excessive noise in the integrated digital-to-analog converter AD5791 is revealed and its connection diagram which eliminates this disadvantage is selected. It is supposed that the application of the discussed in the paper results and recommendations will allow creating an FGM with record level of noise and temperature parameters.

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