Investigation Converter Circuit «Voltage-Current» for Power Calibrator

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Abstract. The paper presents alternative circuits for voltage-current converters to be used in the calibrator of fictitious power. The experimental studies have revealed a number of problems related to the stability of the system in deep feedback and zero level stabilization of the amplifier. The circuit solutions given in the article allow elimination of these problems and improve the accuracy of calibrator current calibration. For example, correction/corrective circuits are used to ensure the stability of the converter at deep depths of the feedback, and operational amplifier based circuit solution and compensation condition are proposed to reduce the additional phase shift. To improve the accuracy of the calibration current values specified by the calibrator we propose to connect the feedback circuit to the measuring current transformer. However, further improvement of the accuracy class of the power calibrator is impossible without modern electronic components.

1. Introduction

Measuring instruments of parameters electrical energy require mandatory verification, which may be performed using automated measurement system [1–4], including the fictitious power calibrator (FPC). This construction of measuring instruments for verification is necessary for the generation of signals arbitrary waveform when the working techniques connected with electrical nets with non-linear distortions [5–7].

In [8], the authors noted that the FPC should contain a voltage-to-current converter (VCC), which would provide the current within a range from 10 mA to 50 (100) A [9]. According to the requirements of normative documents [9, 10], the following metrological characteristics of the calibrator are normalized:

– current calibration error is less than 0.1%;
– instability is not more than 0.05% per 5 minutes;
– distortion is less than 0.2%;
– phase shift between the input voltage and the output current is not more than 0.01°.

The main tasks that need to be addressed:

– to obtain the required values of the VCC output current;
– to provide high metrological characteristics of the converter;
– maintain the VCC stability in deep negative current feedback (NFB) under virtual inductive load.

The article discusses several VCC circuits and the results obtained.

2. Study of power amplifiers circuits for current calibrator

To obtain the required values of the output currents for the power calibrator, a power amplifier (PA) can be implemented in the following three circuits:

– transformerless PA;
– PA with the output transformer;
– combined PA.

Figure 1 shows a circuit for possible implementation of the transformerless PA with the output stage which is a push-pull follower of AB class on power field-effect transistors (IRF740 [11], IRFPF40 [12]). The circuit is powered from two nonstabilized power supplies E_3 and E_4 with earthed middle point (the value of the sources is selected based on the desired value of the load voltage).

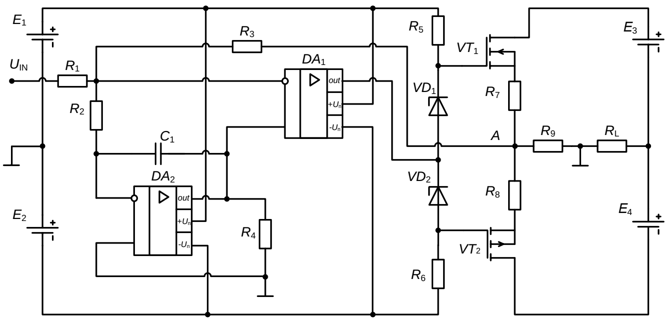


Figure 1. Transformerless PA circuit.

The preamplifier in the circuit is an operational amplifier (op amp) powered from stabilized power supplies E_1 and E_2 with the middle point connected to earth. Resistance R_9 is included between the repeater output (*point A*) and earth. The load is switched between earth and the middle point of the E_3 and E_4 power supplies. The overall current NFB in PA is applied via R_1 and R_3 resistors recordered.

An important condition of the circuit operation is zero DC voltage on R_9, since $I_L = I_9$, then if $U_{R9} = 0$, $I_L = 0$ as well. The problem can be solved through additional feedback application to PA via the integrator using op amps with low offset voltage (for example, OP 177 [13]). The disadvantage of this implementation is that the signal passing through the integrator causes additional phase shift, which is not admissible.

We investigated the possibility of introducing NFB through op amp DA_2 (Fig. 1). In this case, the input signal of the amplifier (input voltage between op amp DA_1) does not affect the phase shift since its value is very small. Figure 2 shows the graph of this amplifier with llowance for the offset voltage of the operational amplifiers $U_{offset1}$ (DA_1), $U_{offset2}$ (DA_2) $U_{offset3}$ (output stage offset voltage).

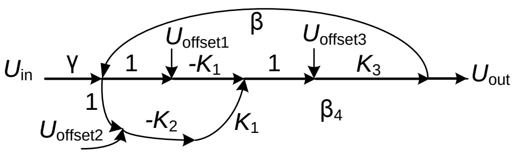


Figure 2. Graph of the transformerless power amplifier.

In the graph $\gamma = \dfrac{R_3}{R_1 + R_3}$; $\beta = \dfrac{R_1}{R_1 + R_3}$; $-K_1$ and $+K_1$ are the transmission coefficients through the inverting and non-inverting DA_1 inputs, respectively; $-K_2$ and $+K_3$ are transmission coefficients for DA_2 and the output stage. Write the following equation (figure 2):

$$U_{out} = -\frac{\gamma}{\beta} \cdot U_{in} - \frac{U_{offset1}}{\beta \cdot (1 + K_2)} - \frac{U_{offset2}}{\beta} + \frac{U_{offset3}}{\beta \cdot K_1 \cdot (1 + K_2)}.$$

Thus, zero offset at point A is determined by operational amplifier DA_2 and this determines the choice. The PA using high-power operation amplifiers, such as PA-05 [14] and PA-07 [15] can be implemented in a similar way.

The fictitious power calibrator "Vector" developed at the Department of Computer Measuring Systems and Metrology, Tomsk Polytechnic University, uses the combined solution: in the circuit shown in figure 1, a single PA working up to 10 A is used without a transformer, and in the range of 10...50 A, the output transformer is used.

In VCC, to obtain high precision calibration of the generated current, one more NFB loop is introduced, in which the current-to-voltage converter is used as a current transformer. Figure 3 shows a VCC circuit diagram, where PA is a power amplifier, DA_1 is a pre-amplifier, T_1 is a current transformer with a transformation coefficient of n_1.

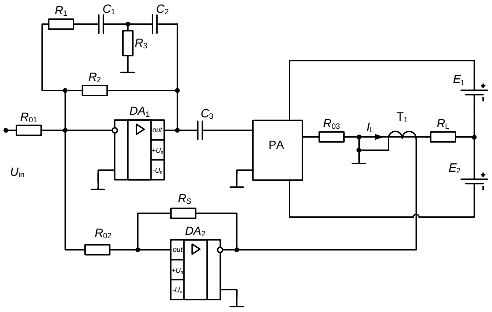


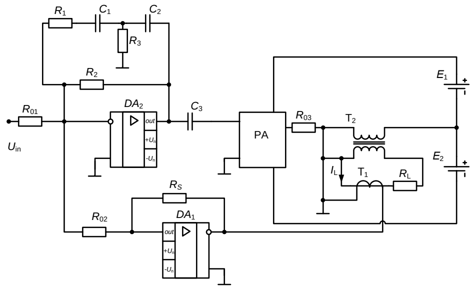
Figure 3. Circuit diagram of VCC with measuring current transformer.

The current-to-voltage converter is performed on op amp DA_2. For this design, the relation between the output current and input voltage is described by the expression

$$I_L = U_{in} \cdot \frac{R_{02}}{R_{01}} \cdot \frac{n}{R_S}, \tag{1}$$

i.e. the ratio R_{02} / R_{01} can be chosen to set the required coefficient for conversion of the input voltage into the load current I_L.

For high-ampere load currents, the output transformer T_2 with a conversion rate of n_2 is switched figure 4.



Figire 4. The VCC circuit with the output transformer.

In the circuit shown in figure 4, the load current is determined by relation (1), but the PA works with the output currents $I_{PA} = I_L / n_2$.

As can be seen from expression (1), the properties of the current transformer (linearity, phase shift) unambiguously determine the calibration accuracy of the VCC output current. When using the current transformer as an output current-to-voltage converter (figure 5), the phase shift φ between E_2 and I_1 according to [16] is equal to

$$\varphi = \psi + \alpha,$$

where ψ is determined by the properties of the current transformer core, and angle α is the inductance of the secondary winding (L_2), its active resistance I_1 and load R_L

$$\alpha = arctg \frac{R_i + R_L}{\omega \cdot L_2}.$$

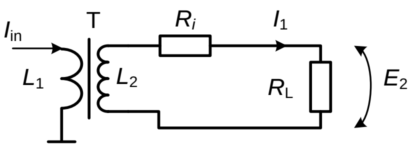


Figure 5. The circuit of the output current-to-voltage converter with current transformer.

Angle α can be considerably reduced using the circuit designs, for example, the circuit shown in figure 6.

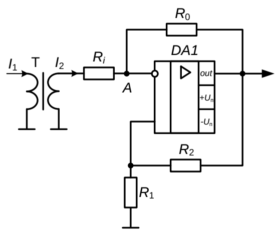


Figure 6. The circuit for reducing the phase shift caused by the inductance of the transformer secondary winding, its active resistance and load.

The input resistance at point A is

$$R_A = \frac{R_0}{1+K}, \tag{2}$$

where K is op amp gain covered by positive feedback (PFB) through R_1 and R_2

$$K = \frac{K_0}{1-K_0 \cdot \beta}, \ \beta = \frac{R_1}{R_1+R_2},$$

where β is the transfer coefficient of the PFB circuit; K_0 is the op amp gain.
Provided $K_0\beta >> 1$, we obtain

$$K = -\frac{1}{\beta},$$

and expression (2) takes the form:

$$R_A = \frac{R_0}{1-\frac{1}{\beta}} = -R_0 \cdot \frac{R_1}{R_2}. \tag{3}$$

From (3), we can write the compensation condition

$$R_i = R_0 \cdot \frac{R_1}{R_2}. \tag{4}$$

Thus, using compensation condition (4), angle α can be reduced to zero. When using current transformer cores made of amorphous alloys, the obtainable angles ψ are of units of minutes that provides the measurement error within 0.1% [17, 18].

A number of current transformers (TO2, TO3-TM, TO3-AS, NRC3-XQ1005 and NRC03A) have been studied. The experimental circuit is shown in figure 7. The tested transformers were loaded with resistance of 100 Ohm (type S2-29, Class 01). The linearity and phase shift were checked by comparing the readings of the precision current transformer (PRISMA-TT/1) and the reference shunt (developed by VNIIM).

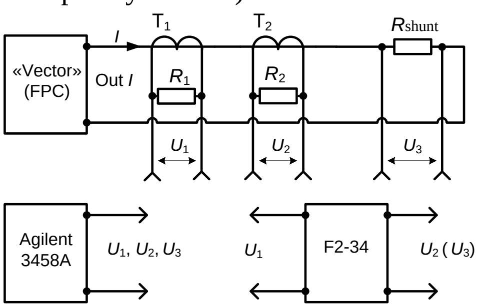


Figure 7. Diagram to study the performance of measuring current transformers.

To measure the voltage, the multimeter Agilent-3458A was used, the phase shift was measured by the phase meter F2-34 at currents of 10 A, 20 A, 30 A and 50 A. The experimental results showed that the tested current transformers have good linearity and low phase shift (with respect to the precision instruments does not exceed 0.01°...0.02°), i.e. their use allows development of VCC with the designed parameters.

It was noted earlier that while designing VCC, the problem to tackle is the stability of the system with very deep NFB. The studies have shown that in case of current calibrator, satisfactory results are obtained using a circuit with the correction circuit (figure 8). The inclusion of this circuit in the pre-amplifier circuit is shown in figures 3 and 4, and gain and phase are shown in figure 9. Hence, the selected resistances R_2 and R_3 can eliminate parasitic oscillations.

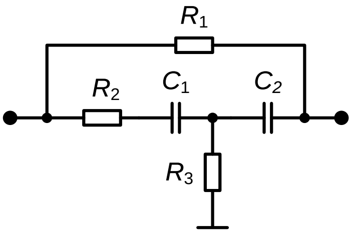


Figure 8. Correction circuit.

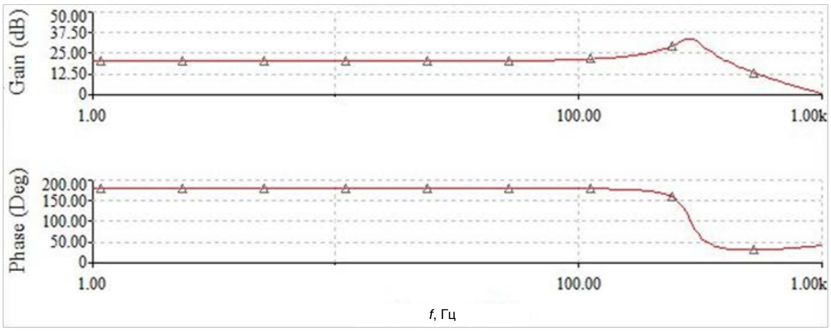


Figure 9. Gain and phase of the correction circuit.

3. Conclusion

Development and implementation of precision voltage-to-current converters faces the problems related to the design, as well as the selection of electronic components (operational amplifiers, transistors, transformers, etc).

The proposed circuit solutions allow elimination of a number of problems such as:

– the frequency correction circuit provides stability of the system with deep negative current feedback;

– variant of compensation for the phase shift of the measuring current transformer reduces the conversion error;

– application of modern operational amplifiers reduces the zero offset.

Thus, the found circuit designs and state of the art electronic components can improve the accuracy of the converters included in the power calibrator and, consequently, improve the calibrator accuracy class.

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