Dual oscilloscope interface with a galvanic isolation

Martin Pospisilik, Petr Neumann and Milan Adamek

Abstract**—** This paper deals with a design and construction of a dual-channel oscilloscope interface which enables concurrent measurement of voltage and current waveforms up to 30 kHz. The operation of the unit is based on a capacitive coupling through and isolation barrier inside a custom integrated circuit. The construction is cheap and easy to be bulit. Two samples of the device were bulit and tested at certain service operations. Based on the experience, several modifications have been proposed. These proposals are included in this paper as well.

Keywords**—**Differential Measurement, Oscilloscope, Isolating Amplifier, Galvanic Isolation

I. Introduction

MOST oscilloscopes use single ended input [2] the negative pole of which is usually grounded to a common ground. This construction allows the operator to measure only those waveforms that are referenced to the ground. If there is a need for differential measurements, two inputs must be involved and the oscilloscope must be switched into a differential measurement mode. Although this practice is satisfactory in most cases, it brings several disadvantages as enlisted below:

- Measurement of one waveform employs two oscilloscope's channels,
- Errors in measurement are cumulated from both channels,
- Common mode rejection ratio is considerably low, especially when the differential voltage is quite low compared to the potential of the measurement points relative to the ground.

As it turned out during service measurements, the differential input is often needed. Therefore the authors decided to construct the proper interface that is described within the framework of this paper.

This work was supported in part by by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089. and by OPVK project CZ.1.07/2.3.00/30.0035.

Martin Pospisilik is with Tomas Bata University in Zlin, Faculty of Applied Informatics, Nad Stranemi 4511, 760 05 Zlin, Czech Republic. He is now at the department of Computer and Communication Systems (e-mail: pospisilik@fai.utb.cz)

Petr Neumann is with Tomas Bata University in Zlin, Faculty of Applied Informatics, Nad Stranemi 4511, 760 05, Zlin, Czech Republic. He is now a researcher at the Department of Electrical engineering and Measurement (e-mail: neumann@fail.utb.cz)

Milan Adamek is with Tomas Bata University in Zlin, Faculty of Applied Informatics, Nad Stranemi 4511, 760 05, Zlin, Czech Republic. He is the head of the Department of security engineering (e-mail: adamek@fail.utb.cz)

II. Requirements and Prerequisities

The initial requirements were as follows:

- Two different channels for voltage and current measurements,
- Possibility of the zero level correction,
- Measured voltage range ± 20 V,
- Measured current range ± 1 A,
- Isolation strength between input and output at least 1.5 kV,
- Frequency range DC to 30 kHz.

On the basis of the above mentioned requirements it was decided to apply the isolation amplifier ISO124 [3] and to equip it with additional output low pass filter. The construction of the differential inputs and the output low pass filters is based on JFET operating amplifiers TL081 [4].

A. Isolating amplifier ISO 124

The ISO124 is a precision isolation amplifier incorporating a duty cycle modulation-demodulation technique. The signal is transmitted digitally across a 2pF differential capacitive barrier. With digital modulation the barrier characteristics do not affect signal integrity, resulting in excellent reliability and good high frequency transient immunity across the barrier. Both barrier capacitors are imbedded in the plastic body of the package. No external components are required for operation. The key specifications are 0.010 % max nonlinearity, 50 kHz signal bandwidth, and 200 μV/°C V_{OS} drift. A power supply can lie in the range of ±4.5 V to ±18 V [3].

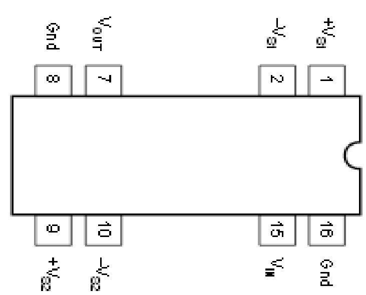

Fig. 1 DIP package connection diagram of ISO124 (top view) [3]

The package of the device is adjusted to allow achieving the continuous isolation voltage of 1,500 V_{RMS}. Therefore the

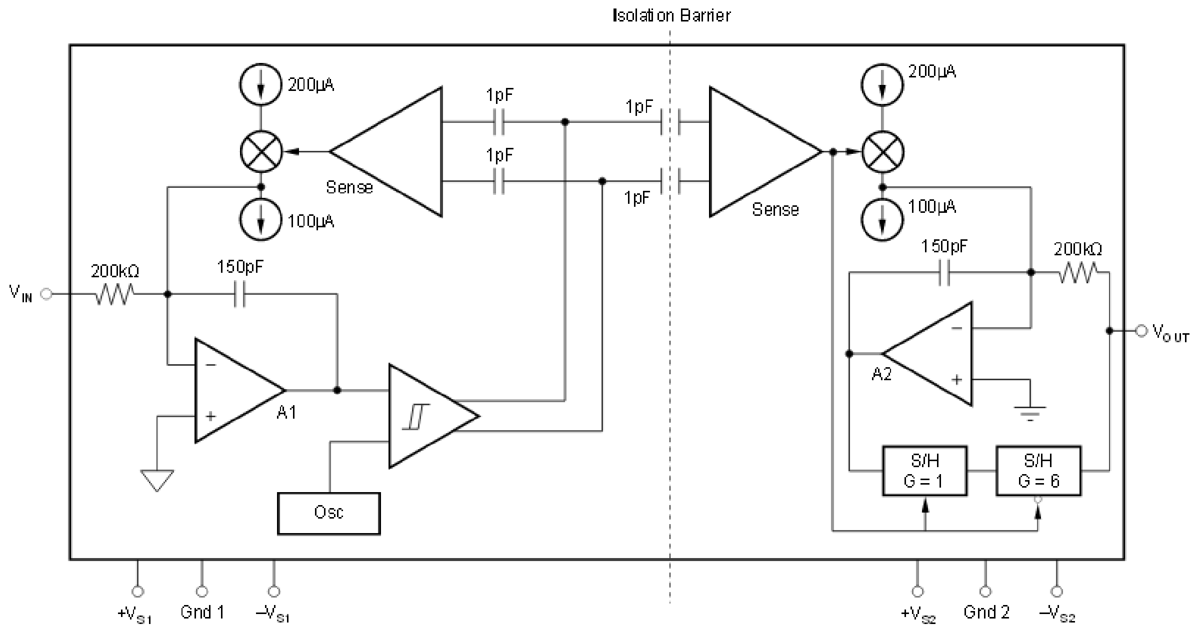

Fig. 2 Block diagram of internal circuits in ISO124 [3]

amplifier is encapsulated in 16-pin plastic DIP or 28-lead plastic SOIC package. The connection of pins is described in Fig. 1.

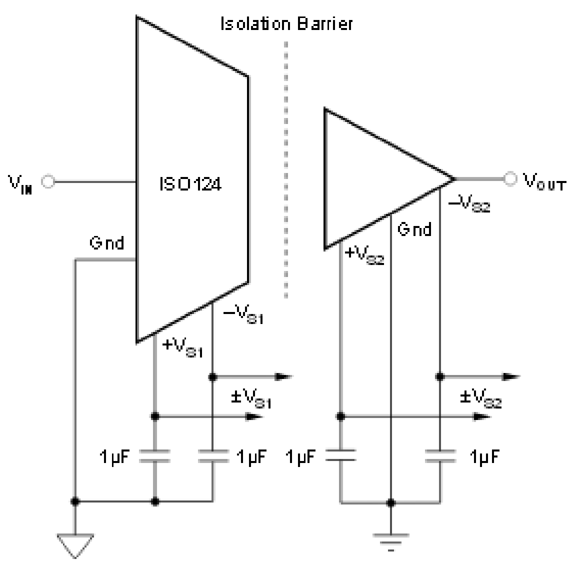

Fig. 3 Basic signal and power connections of ISO124 [3]

In Fig. 2 the block diagram of internal circuits in ISO124 can be found. The input amplifier A1 integrates the difference between the input current and the switched ± 100 µA current source. The internal oscillator forces the current source to switch at the frequency of 500 kHz. The complete block at the front-end of the isolation barrier creates a modulator that produces triangular wave at the frequency forced by the internal oscillator and the duty cycle proportional to the voltage at the input pin V_{IN}. At the back-end of the isolation barrier there is a sense amplifier that detects the signal transitions across the barrier and drives a switched current source into the integrator A2. The output stage balances the duty-cycle modulated current against the feedback current through the 200 kΩ feedback resistor, resulting in an average value at the V_{OUT} pin. [3]. As a result of the operation, 20mV ripple at the frequency of 500 kHz is present at the output of the circuit. This can be removed by additional low pass filter. The basic signal and power connections of the amplifier are depicted in Fig. 3.

In figures 4 to 7 the typical performance of the amplifier according to its datasheet [3] is depicted.

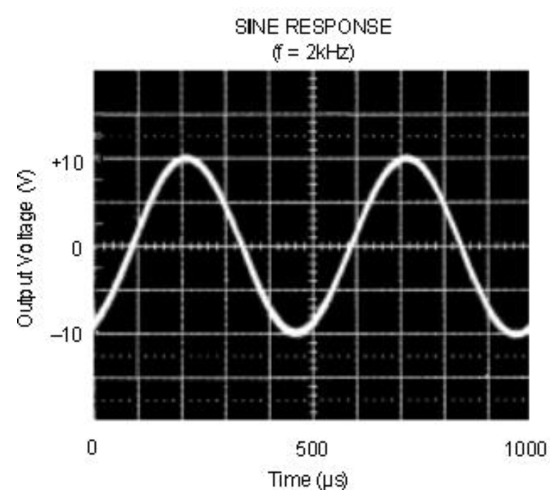

Fig. 4 Sine response of ISO124 on the signal with f = 2 kHz and V_{PP} = 20 V [3]

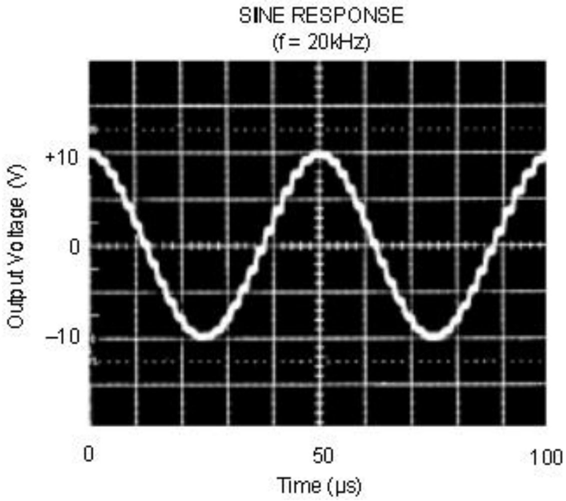

Fig. 5 Sine response of ISO124 on the signal with f = 20 kHz and V_{PP} = 20 V [3]. The effect of sampling can be observed here.

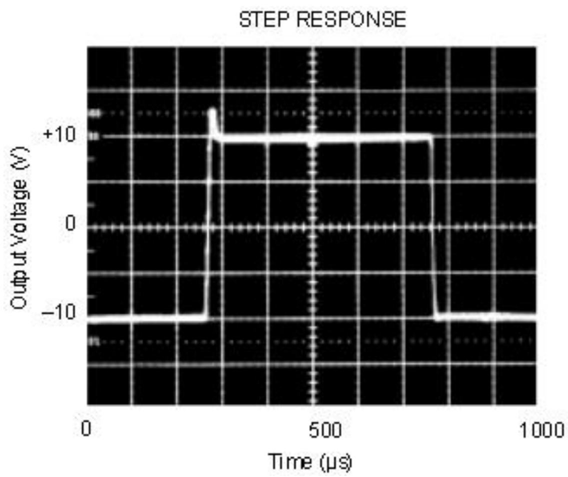

Fig. 6 Step response of ISO124 to a pulse wide 500 µs [3]

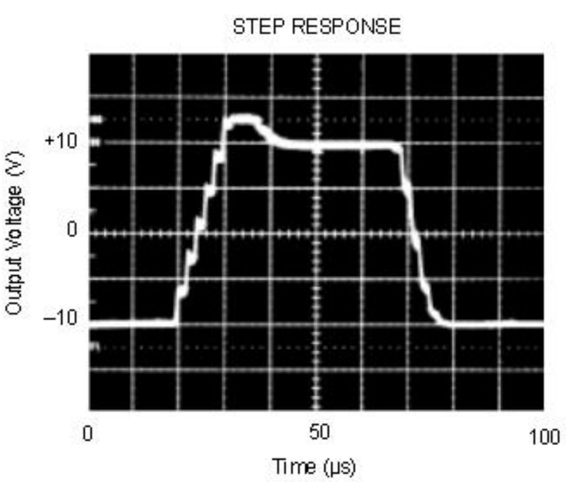

Fig. 7 Step response of ISO124 to a pulse wide 50 µs [3]

B. Operating amplifier TL081

The TL081 is a low cost high speed JFET input operational amplifier with an internally trimmed input offset voltage. The device maintains a large gain bandwidth product and fast slew rate. The noise and offset voltage drift is also at low levels. The absolute voltage offset can be set by an external trimmer. According to [4], the parameters of the device are as described in Table I.

Table I Parameters of TL081 [4]

Parameter	Value
Input bias current	50 pA
Input noise voltage	25 nV/$\sqrt{\text{Hz}}$
Gain bandwidth	4 MHz
Slew rate	13 V / µs
Supply current	1.8 mA
Input impedance	10^{12} Ω

The typical connection of TL081 including the zero level correction is depicted in Fig. 8. The internal connection of the amplifier is depicted in Fig. 9.

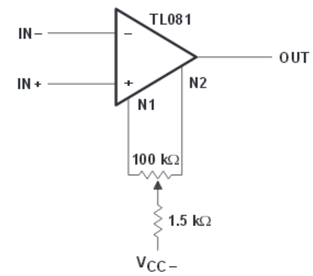

Fig. 8 Basic connection diagram including zero level setting [4]

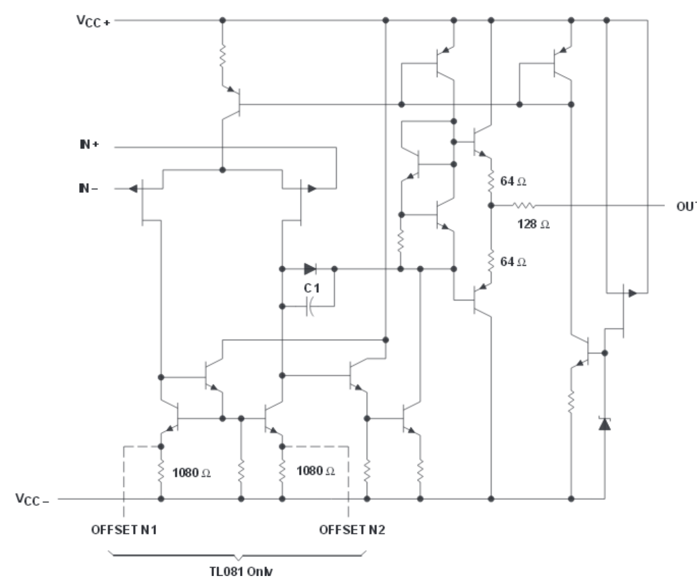

Fig. 9 Internal connection of TL081 [4]

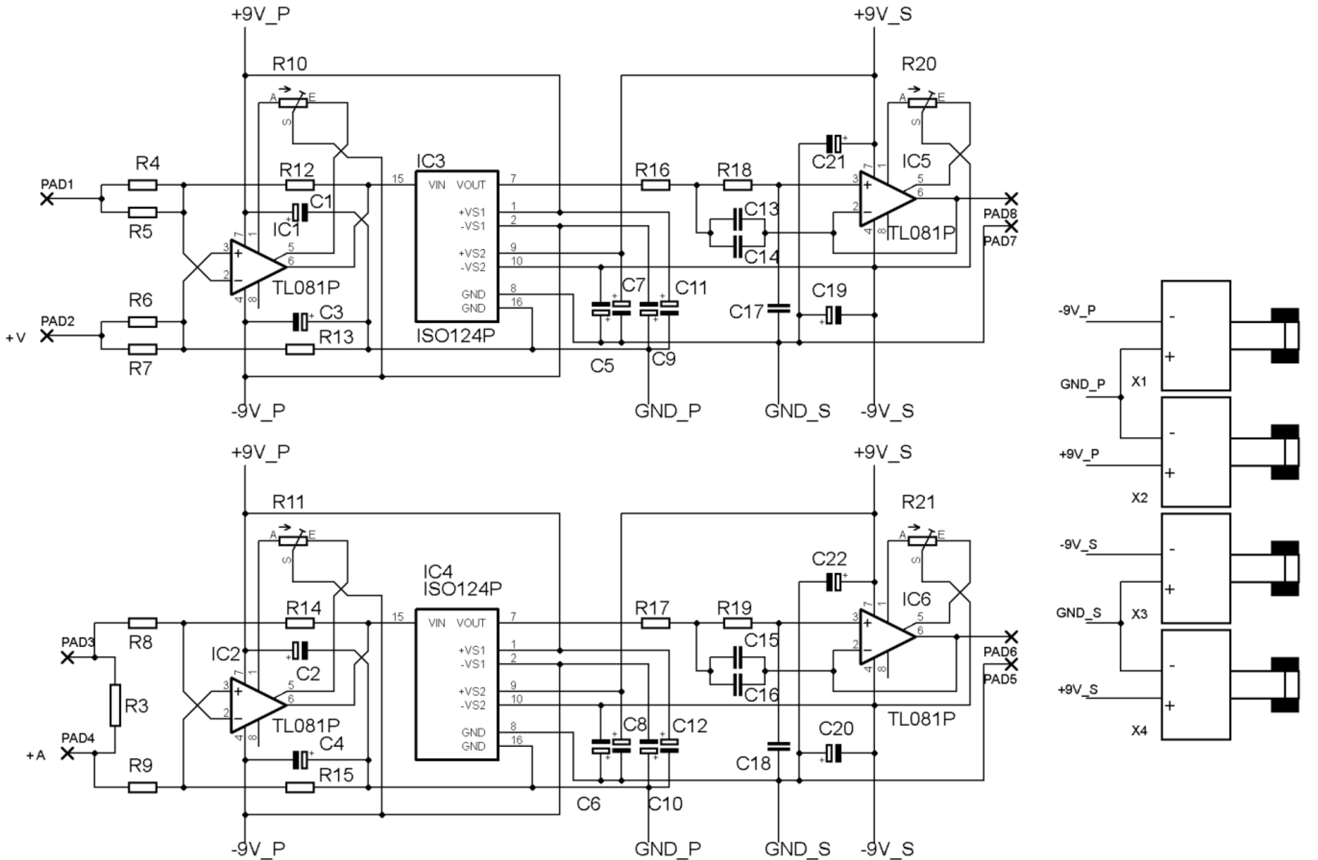

Fig. 10 Isolating interface circuit diagram

III. The Construction

The dual channel isolating amplifier was constructed in two versions. One of them require an external power source while the second one, the circuit diagram of which is depicted in Fig. 10, employs four independent 9 V batteries. This solution is more convenient for using the device at servicing outside the laboratory.

The device is constructed on a single double sided printed circuit board, including the battery holders. The inputs and outputs of the channels are equipped with pins to which the cables with crocodile clips can be attached. In the neighborhood of each of the operating amplifiers there are precise trimming resistors allowing accurate zero level setting. The printed circuit board is strictly divided into primary and secondary part. These parts are coupled only by means of the ISO124 isolating amplifiers.

Four 9V batteries are mounted in appropriate holders X1 to X4. The power supply nets are different for the “primary” (frontend of ISO124) and the “secondary” (backend of ISO124) part. Also the grounds are strictly separated. The “primary” power supply nets are marked with the letter P (+9V_P, GND_P, -9V_P) while the “secondary” power supply nets are marked with the letter S (+9V_S, GND_S, -9V_S). All power supply inputs of the pertinent integrated circuits are blocked by tantalum capacitors as close to the appropriate pins as possible. The power paths on the printed circuit board were designed carefully in order to protect the output of the device from noise caused by switching of the circuitry inside the isolating amplifiers (see Fig. 2).

The input of the “voltage” channel is at pins PAD1 and PAD2. The sign “+” shows the polarity of the input. This sign is also depicted at the printed circuit board. The input of the “current” channel is at pins PAD3 and PAD4, also marked with the appropriate sign. The input stages are realized by means of operating amplifiers IC1 and IC2 in a conventional connection. The input resistance of the “voltage” channel is approximately 50 kΩ. The current is measured by means of the shunt resistor R3 the resistance of which is 0.1 Ω.

The output filters are based on the operating amplifiers IC5 and IC6. The values of the appropriate devices were set so the 2^{nd} order Butterworth’s transfer function was achieved. Consequently, smooth modification of the device values were made so higher Q was achieved close to the corner frequency. The corner frequency is tuned to approximately 35 kHz. The measured frequency response of the channels is depicted in Fig. 11. Alternatively, the output filter can be based on current feedback operational amplifiers [10].

The outputs of the relevant channels are connected at pads 5, 6, 7 and 8.

In Fig. 12 there is a photo of the battery-powered device. The device list is enlisted in Table II. Some of the positions are omitted for the battery-powered version that is described within the framework of this paper.

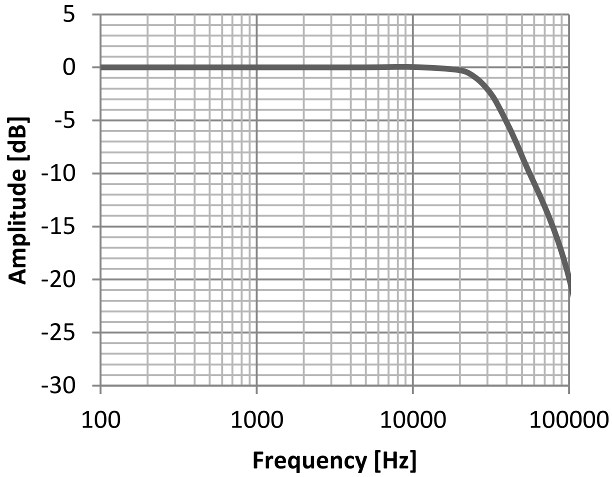

Fig. 11 Typical frequency response of the isolating interface

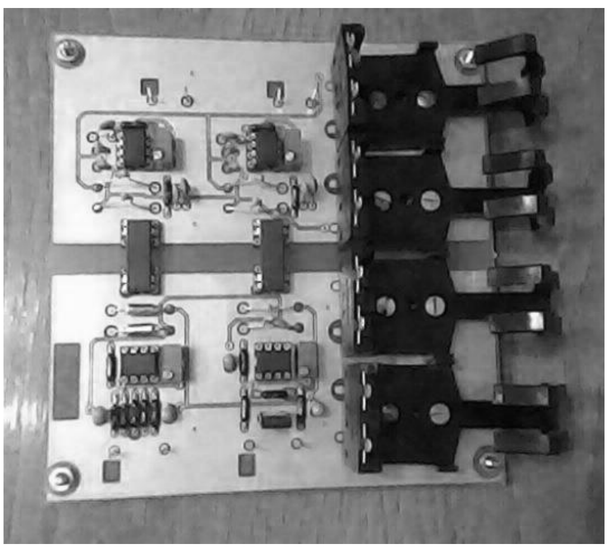

Fig. 12 Battery powered version of the isolating interface

Table II Device list

Position	Value	Note
R3	0.1 Ω	1 %, 1 W
R4, R5, R6, R7, R14, R15	100 kΩ	1 %
R8, R9	1 kΩ	1 %
R10, R11, R20, R21	100 kΩ	Multiturn trimmer
R12, R13, R16, R17, R18, R19	10 kΩ	1 %
C1 to C12, C19 to C22	1 - 10 μF	tantal
C13, C15	68 pF	ceramic
C14, C15	680 pF	ceramic
C17, C18	330 pF	ceramic
IC1, IC2, IC5, IC6	TL081	See [4]
IC3, IC4	ISO124	See [3]
X1 to X4	9V battery holders	

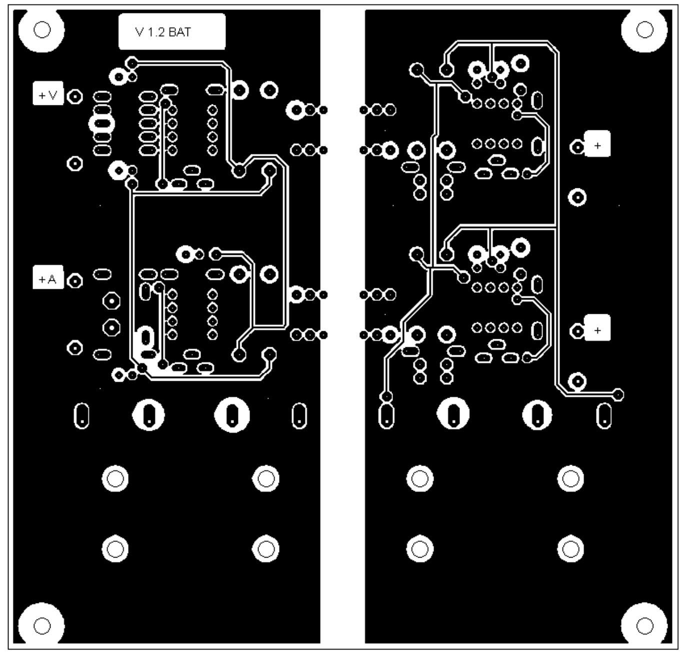

Fig. 13 Printed circuit board – top side

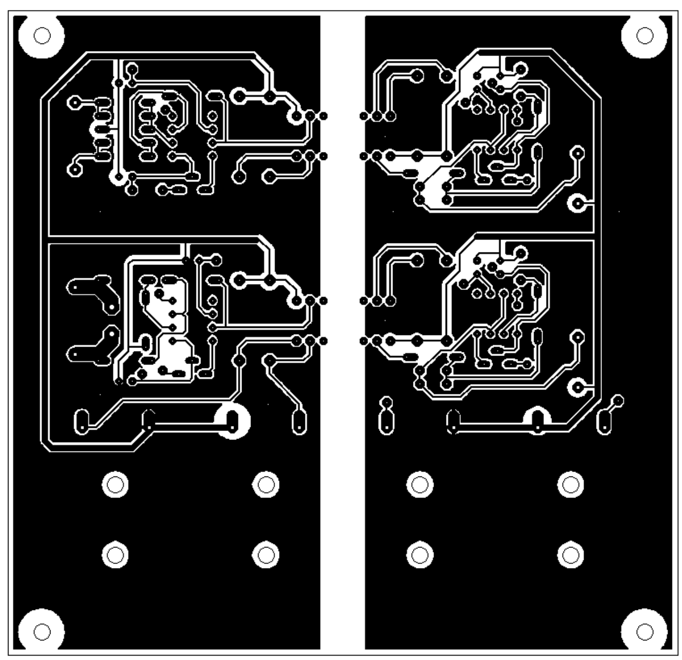

Fig. 14 Printed circuit board – bottom side

IV. Modifications

On the basis of experience gained with the construction, several modifications have been proposed. The most useful modification proposals are described below.

A. *Single battery power supply*

It is inconvenient to power the circuit by 4 large 9V batteries. An efficient solution can be made when a charge pump or transformer-based voltage converters are used.

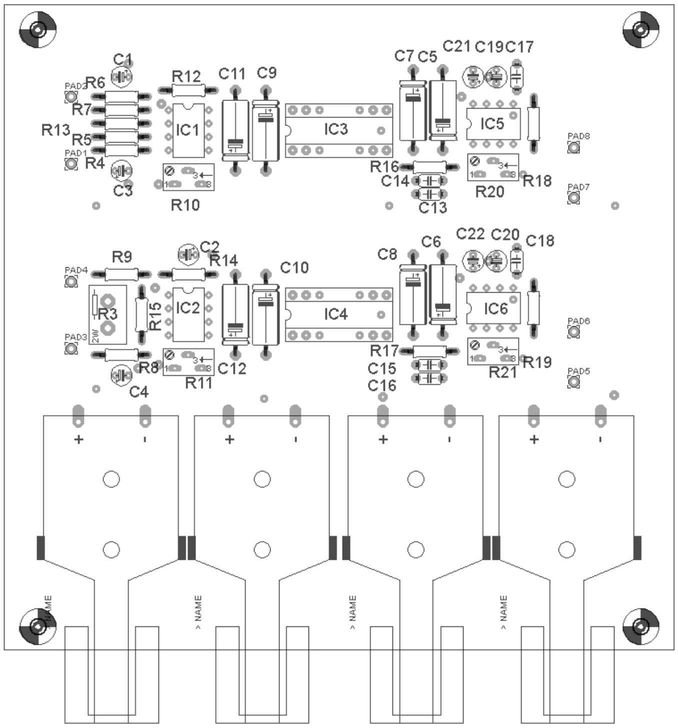

Fig. 15 Displacement of devices on the printed circuit board

Because the quiescent current of ISO124 is lower than ± 7 mA [3] and the quiescent current of TL081 is lower than ± 1 mA, the total power consumption of each branch can be considered to be lower than ± 20 mA. For these purposes a charge pump seems to be an efficient power supply, bringing an advantage of an omitted transformer.

A simulation schema of a symmetrical power supply can be found in Fig. 16. As a square wave voltage source a 555 timer [7] is used, operating at a frequency of approximately 75 kHz. Two voltage multipliers are coupled by capacitors C3 and C14. While the upper one does not change the polarity of the voltage, the second one does so. A simple voltage stabilizer set to approximately 10 V is connected at the back-end of each multiplier. There is no DC coupling between the outputs of the circuit, as both output branches are decoupled by means of capacitors C3, C8 and C14. The isolation voltage is then given by the quality of these capacitors. For the purposes of the simulation, the load of the outputs of the circuit is composed of current sources I1 and I2 whose polarities are reversed.

The performance of the circuit was simulated by Multisim software and the outputs of the simulation are depicted in the figures below.

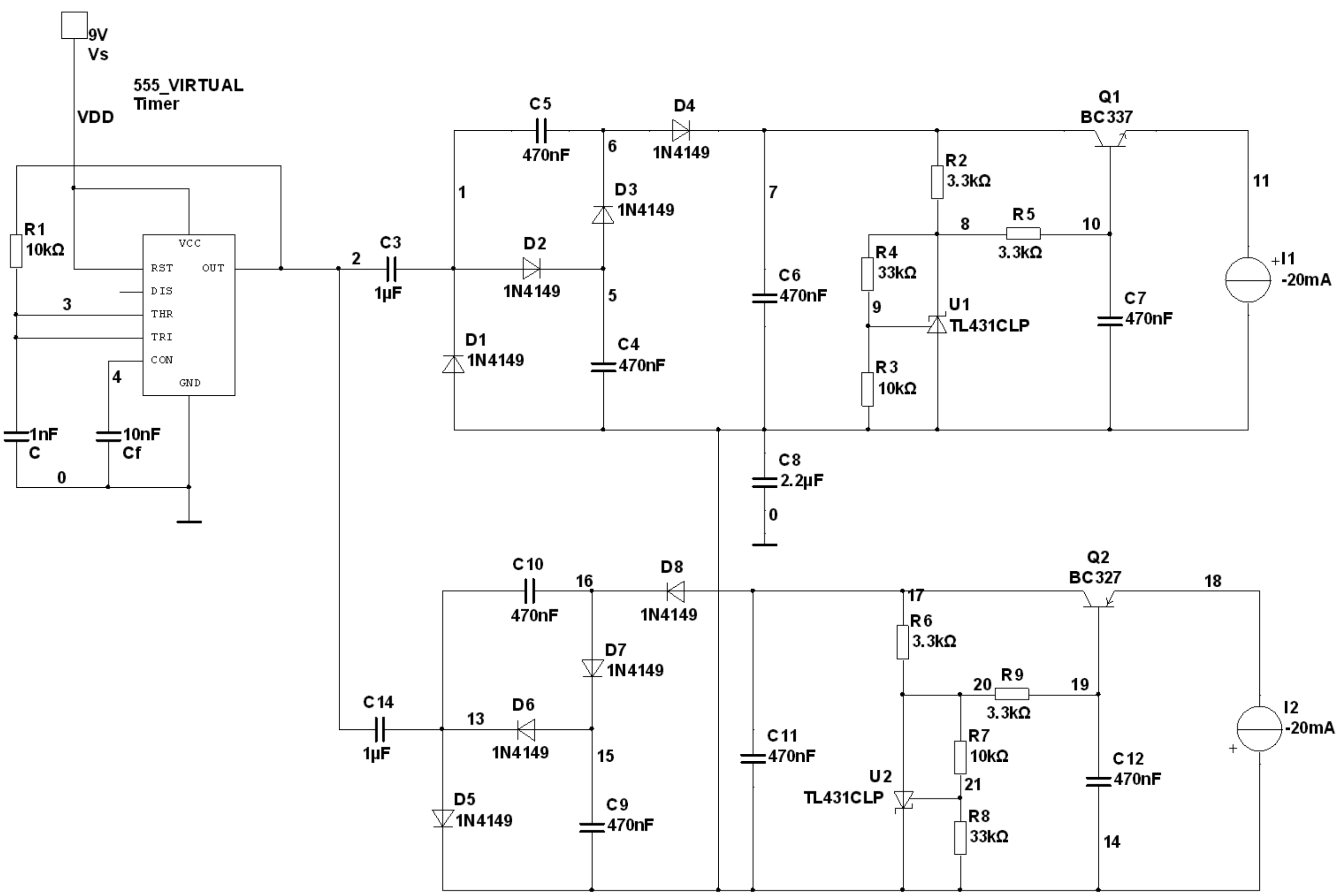

Fig. 16 Symmetrical voltage converter and stabiliser without a DC coupling

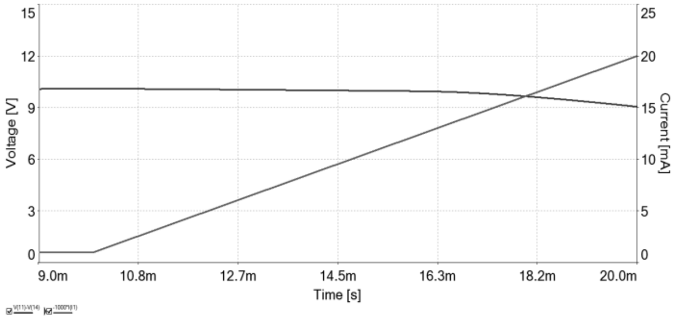

Fig. 17 Output voltage versus load current

In Fig. 17 the dependence of output voltage on the output current is depicted. Worst case is considered, in which both branches are loaded up to 20 mA. The output voltage decreases by approximately 10 % at full load.

In Fig. 18 the voltage ripples for load of 10 and 20 mA are displayed. When the output is fully loaded, the ripple voltage is approximately 300 μV_{pp}.

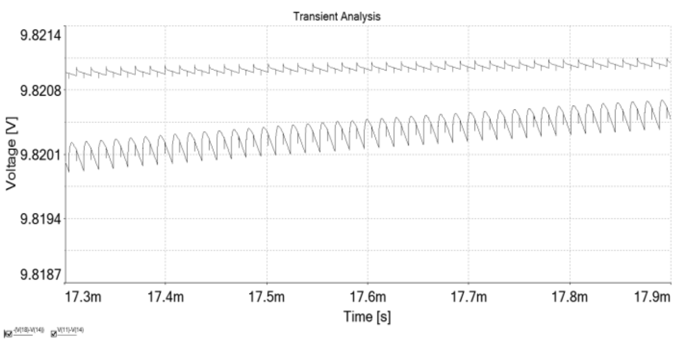

Fig. 18 Voltage ripple at loads of 10 and 20 mA

As the current at the output of NE555 or similar timer chip is limited, for two different power supplies ("primary" and "secondary") two drivers are needed. When both drivers are powered from one battery, the maximum isolation voltage is given by the quality of the decoupling capacitors. When each driver is powered from a separate battery, the capacitor C8 can be omitted and the isolation between the primary and secondary sides is not affected by the power supply circuit.

B. Current input improvement

According to the experience it was realized that the differential amplifier at the current input (IC2 in Fig. 10) suffers from slight voltage offset. This is given by the net of feedback resistors. As a consequence of this offset, the appropriate trimming resistor must be set close to its stop position. The cause of the offset is obvious from the picture in Fig. 19 that displays a net of resistors around the relevant operating amplifier. The output voltage of the operating amplifiers reaches the level at which the voltages at both inputs are equal. Theoretically, if there was no voltage offset at the input of the amplifier, this consideration would be fulfilled for both input and the output voltage equal to zero. Unfortunately, in practice the operating amplifiers suffer from considerable input voltage offset. When the feedback net is connected as depicted in Fig. 19, the input voltage offset is amplified as well as the input signal.

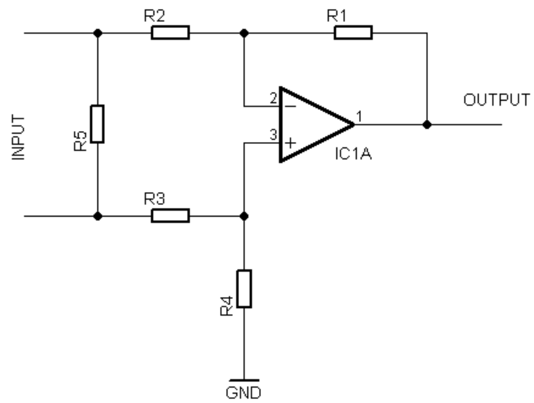

Fig. 19 Connection diagram of a current input of the interface

Using the same values of resistors as in the current input interface, the circuit diagram was simulated and its sensitivity to the input voltage offset of the amplifier was observed. A dependence of a typical output offset on the value of R5 resistor is depicted in Fig. 20.

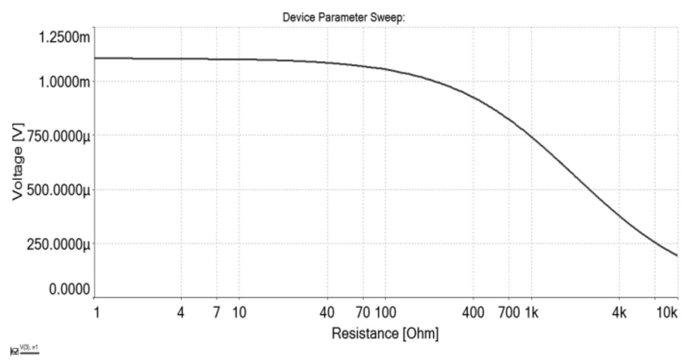

Fig. 20 Dependence of a typical output voltage offset on the value of the resistor R5

Moreover, the DC operating point of this circuit is also affected by tolerances of the resistors. Generally said, that differential amplifier as depicted in Fig. 19 is not appropriate for high amplification factors. This problem can be solved by implementing of instrumentation amplifier, the simulation diagram of which is depicted in Fig. 21.

The instrumentation amplifier consists of two stages. The first one stage employs two different amplifiers that ensure the gain of the differential input. The gain is set by the resistor R3 for both amplifiers. The second stage consists of a differential amplifier the amplification factor of which is equal to 1. Because a quad operational amplifier is used, there are no connection pins for zero compensation trimmers. The zero compensation can be done according to [9] by adding a small voltage source in series with the resistor R7.

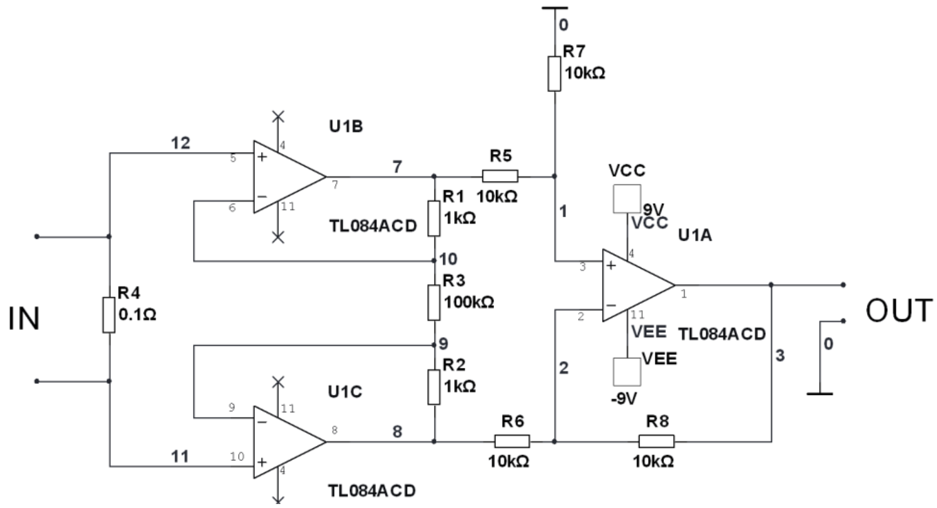

Fig. 21 Suggested instrumentation amplifier – simulation schema

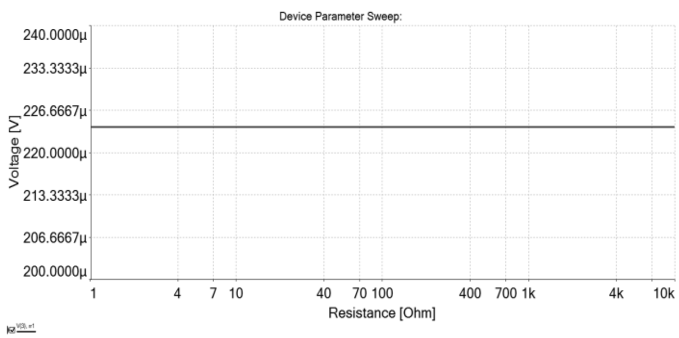

Fig. 22 Dependence of a typical voltage offset of the instrumentation amplifier depicted in Fig 21 on the resistance of the resistor R4

The suggested instrumentation amplifier depicted in Fig, 21 was simulated. It was shown that its voltage offset is not affected by the current sensing resistor (R4 in Fig. 21). The offset of the circuit can be adjusted by connecting R7 not to the ground, but to a symmetrical adjustable voltage reference.

V. Conclusion

This paper provides a description on a construction of a dual channel galvanically isolated interface for an oscilloscope that enables measurement of differential voltages or currents of those waveforms the bandwidth of whose does not exceed approximately 30 kHz. The device utilizes the isolating amplifier ISO124 with discrete-time modulation.

The device has been built in two versions. One of them requires external power supply while the second one is powered from batteries mounted directly on the device. This version is successfully used at service operations outside the laboratory.

According to the experience gained during the operation of the interface, a set of improvements was suggested. The two of these improvements are introduced in this paper. The first one eliminates the necessity of employing four 9V batteries and the second one increases the stability of the current input voltage offset.

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