Analog Design Contest 2013 Project Report

PROJECT TITLE: **The device for automatic salt addition in water food solutions**

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Qty.	TI Part Number & URL	Qty.	TI Part Number & URL
1	LM317-N	4	TL431
1	LM337-N	1	INA128e
2	TL081	1	LM35
1	TL082	1	LM311
3	TL084	1	MPY634

Project abstract:

The device that helps to automate the process of water food solutions salting is presented in the paper.

The basis of the instrument operation is the measurement of solution resistance and its comparison with a standard scale drawn up on the basis of the experts tastes sensations.

On the results of measurement the salt batcher switches on automatically.

Introduction

Often cooking water food solution is accompanied by addition of salt in it. So the cook can make a desirable taste of a dish. Usually a cook is guided by his or her own empirical experience which has been accumulated from indications of gustatory receptors of tongue. Whereupon he makes a choice of salt quantity for making such salinity of a water food solution as it is necessary for him. Therefore process of salting is realized manually.

One of the most exact and relatively simple way of a quantity estimation of substance structure in water solution is the conductometry (conductivity measurement). For this purpose it is necessary to have the preliminary calibration curve. This curve illustrates the dependence of electrical conductivity from concentration of substance (NaCl). In turn, to trace the connection between salinity taste sensations and salt concentration change in water food solution for an ordinary person is possible with the help of electrical conductivity measurement to perform water food solution salting to desirable condition; and the process is to be automatized. The described principle is put in a basis of the device for automatic salt addition in water food solutions.

Motivation for project

Our team is studying at Radioengineering department of National Technical University of Ukraine “Kyiv Polytechnic Institute”. We have already gained theoretical knowledge on analogue and digital electronic circuits design. So we decided to use it practically by working out our own design. Now a lot of attention is paid to electronics which is the intermediary between the person and the nature. The person is an “analogue” system. Working out the analogue design allowed us to deepen our knowledge about human and nature.

Theoretical background

Water food solutions such as chicken bouillon, buckwheat soup, red borsch can be considered as an electrolytic solution of NaCl (hereinafter referred to as “salt solution”) from the point of view of electrochemical changes. Electrical conductivity (and resistance) of salt solution is considerably influenced by 2 factors: concentration of salt (NaCl) and temperature in a solution at the moment of measurements.

Electrical conductivity is supposed to be considered as a function of electrolyte (NaCl) dilution. In this case, the conductance increase is observed at the increase in concentration of an electrolyte, correspondingly the electric resistance decrease is observed. Function is nonlinear monotonously diminishing for electric resistance and monotonously increasing for conductance. A function maximum (or minimum) is also miscellaneous for different electrolytes.

Dependence conductivity of salt solution from temperature is described by approximate Kohlrausch formula:

$$\chi(t) = \chi(25^{\circ}C)\cdot[1+0,22\cdot(t-25)], \qquad \textbf{(1)}$$

where $\chi(25^{\circ}C)$ is conductivity at temperature $t = 25^{\circ}C$;

The salty taste is directly proportional related with concentration of an

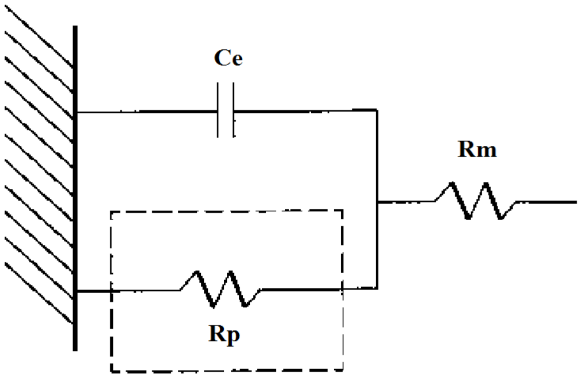

Fig 1. Electrical equivalent circuit of an electrode.

Rm - electrical resistance of salt solution;

Rp - polarization resistance;

Ce - capacitance of the electrode.

electrolyte that is caused by presence of Na^+ ions at the solution.

Experiments proved that concentration of salt solution for normal salty taste of the average person should be in $0,25\% \div 1,25\%$ limits from the total volume of solution.

10% salt solution was accepted to be considered as upper bound for the concentration at which the solution is tasted as excessively salty.

For water food solution (chicken bouillon, buckwheat soup, red borsch) we made a decision to conduct additional experimental researches.

The aims of experimental researches are:

- Definitions of functional dependencies form of electric resistance from concentration NaCl, described above.
- Definitions of a range for maximum points of electrical resistance for different water food solutions.

Electric resistance can be found by Ohm's law.

For this purpose two electrodes are submerged into salt solution through which an electric current with known value is passed. Voltage is measured from the same electrodes.

For obtaining high accuracy measurements of electric resistance:

a) Measurements should be led at alternating current. Using a direct current is undesirable process for electrolysis.

b) It is necessary to minimize influence of polarization process. The Rp is quantitative estimation (**Fig.1**). For this purpose the frequency of an alternating current should meet a condition $f \geq 10kHz$. Also the special material for an electrode, for example, silver should be used.

c) It is necessary to minimize the influence of capacitance of the electrode (**Fig.1**). For this purpose it is necessary to minimize the surface of an electrode, for example, by reducing its geometrical sizes.

d) It is necessary to carry out temperature correction of electric resistance measurements. Temperature influence is shown in the equation **(1).**

Experimental researches

Tools for the experiment: Laboratory flask 1 liter, sodium chloride (NaCl), metering spoon 10mg, alternative current source with amplitude 1 mA and frequency 10 kHz, oscilloscope UT2042B.

We chose 4 types of water food solutions: distilled water, chicken bouillon, buckwheat soup, red borsch.

The aim of the experiment: To establish the relationship between taste sensations of salinity and electrical resistance of water food solution by means of the expert estimations for various type of water food solution (the distilled water, chicken bouillon, buckwheat soup, red borsch).

The methodology of the experiment: The laboratory flask was fully filled with one of types of water food solutions in each case at temperature of $25^{\circ}C$. Electrodes were submerged into salt solution. Alternative current, from an alternating current source (**Fig. 4**) flows through the same electrodes. The amplitude of current is equal to 1mA and its frequency is 10 kHz. Then portions of salt were gradually added into the flask by means of a metering spoon in the laboratory and the voltages on electrodes were measured. The respondents tested salt solution simultaneously with measurements. And then the estimations were given on the 0-10 Numeric Scale. Where, 0 mark - a condition of "absolutely not salty" and 10 mark - a condition "excessively salty". 100 respondents (students of our faculty) participated in this experiment. The results of estimations (Q mark) were averaged and resulted in **Table 1.**

Table 1

T=25°C	Water			Chicken bouillon			Buckwheat soup			Red borsch		
Concentration	U, mV	R, Ohm	Q, mark	U, mV	R, Ohm	Q, mark	U, mV	R, Ohm	Q, mark	U, mV	R, Ohm	Q, mark
0	4350	9425	0	1852	4012,667	0,2	730	1581,667	0,4	260	563,3333	0,5
10	1020	2210	1,3	526	1139,667	0,9	350	758,3333	0,6	199	431,1667	0,7
20	694	1503,667	1,5	397	860,1667	1,6	250	541,6667	1,5	120	260	1,6
30	560	1213,333	2,1	318	689	3,4	155	335,8333	2,8	109	236,1667	2
40	470	1018,333	2,6	261	565,5	5,8	110	238,3333	4,2	99	214,5	3,7
50	426	923	3,3	211	457,1667	7,6	105	227,5	5,5	79	171,1667	4,1
60	383	829,8333	4,9	176	381,3333	8,4	90	195	7	68	147,3333	5
70	353	764,8333	6,7	157	340,1667	8,8	84	182	8,5	60	130	6,2
80	330	715	7,3	138	299	9,4	78	169	9	53	114,8333	7,6
90	308	667,3333	8	121	262,1667	9,7	72	156	9,7	46	99,66667	9,1
100	290	628,3333	9,6	102	221	9,9	69	149,5	9,9	44	95,33333	9,9

From **Table 1** we can see that

a) Values of estimations (Q) linearly depend on concentration of salt NaCl in investigated water food solutions.

b) Point of maximum for dependence of electric resistance from concentration of salt NaCl at different water food solutions changes approximately in 10 times.

c) It has been noticed that taste estimations of different respondents differ. So women are more sensitive to smaller concentration of salt.

d) It is noticed that also a direct component is present for all 4 cases at measurement voltage signal. It is caused by the chemical nature of salt solution, namely different ionic mobility, and it is true for any salt solution. Therefore it is necessary to compensate the influence of a direct component on the measurements result.

Experimental data gained in (**Table 1**) were approximated in MS Excel. We established a better form of approximating function.

$$\chi(c) = -A \cdot \ln(c) + B, \quad \textbf{(2)}$$

It gave the closest value of determination factor to 1 for all 4 cases; A, B - empirical coefficients.

Implementation

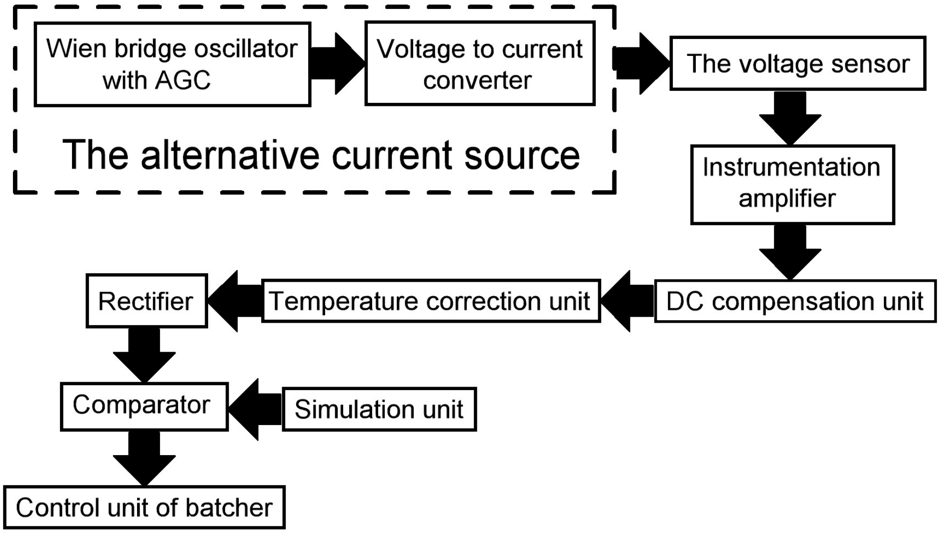

Fig. 2. The block diagram of the device.

The device concept:

The device was designed according to the block diagram (**Fig.2**). The sinusoidal current with constant amplitude is passed through two electrodes submerged into salt solution. The sinusoidal current is formed from a signal generator by transformation of voltage to current. The voltages on electrodes will be proportional to electrical resistance of water food solution (concentration of salt). Voltages are measured on electrodes by means of instrumental amplifier for common mode noise rejection. The signal from instrumental amplifier after compensation and temperature correction is detected and comes on the comparison unit. From the other side a reference signal is applied on the comparison unit. The reference voltage should be adjusted. For the purpose of scale linearization the reference voltage should be formed by the logarithmic resistor. The comparison unit operates the batcher of salt. Until the salinity of water food solution does not achieve the certain level, salt pours out at water food solution, adding of salt is stopped when desirable salinity is achieved.

Benefits of Texas Instruments products:

Among variety of operation amplifiers (OpAmp) presented by Texas Instruments, series TL08x (TL081, TL082, TL084) with several actual advantages attracted special attention to our design:

- Low cost
- JFET, High Input Impedance
- Input Voltage Range ±15V, Supply Voltage ±18V
- Low Supply Current
- Low Input Noise Voltage and Current
- High Slew Rate
- Wide Gain Bandwidth (It is guaranteed high gain at 10 kHz)

Simultaneous presence of all these properties makes an optimal choice of these OpAmps for all electrical circuits at our project.

Unlike other manufactures of instrumentation amplifiers the INA128 from Texas Instrument has rather low cost and in many cases – better electrical performance. First of all it has low own noises. Besides, usage of the processing methods for identity raise of gain channels at INA128e allows obtaining high common-mode rejection (CMR minimum 120 dB).

The multiplier MPY634 also has good electrical performance, but it is expensive. On the other hand, it is a wideband that makes it useful for considerable quantity of circuit designs.

LM317 and LM337 were used as effective alternatives for our project that are rather low-cost and fail-safe voltage stabilizers.

Power supply

The low-power linear Power Supply has been chosen (**Fig.3**). The whole circuitry is feed from dual outputs ± 15 V and direct current of 200 mA. Symmetrical voltage is especially necessary for operation amplifiers. This Power Supply provides less noise and ripple unlike switched-mode power supply. Power supply has protection from short circuit or overload that could damage the supply. Two adjustable 3-terminal voltage regulators TI: LM137 - for positive voltage +15V and LM337 - for negative voltage -15V are used for voltage stabilization at the adjective levels.

The alternative current source

The alternative current source consists of two parts: Wien bridge oscillator with an automatic gain control (AGC) (**Fig.4**) and voltage to current converter (VCV) (**Fig.5**). The alternative current with amplitude 1 mA and frequency 10 kHz is formed at VCV output. The high output resistance ($Rout$) is required for current source. Therefore we designed the original circuit of VCV (**Fig.5**) at which on frequencies below 100 kHz:

- $Rout$ to 2 MOhms;
- the range of load resistance variation (load resistance is a resistance of salt solution Rm) is 50 Ohm - 10kOhm
- nonlinearity of a current in $Rm \leq 1\%$;
- no direct component at output signal ;

Principle of its work (**Fig.5**):

The base elements in the circuit design are two direct current sources. Each consists of the operational amplifier and the transistor. $DA2.C$ и $VT2A$ - positive direct current source with output current $I_{s^+} = U_{VR1} / R16$; $DA2.D$ и $VT2B$ - negative direct current source with output current $I_{s^-} = U_{VR2} / R17$; The bipolar current source is gained connecting them together (**Fig.5, point A**). We used complementing pair of field effect transistors (N and P-channel in one package) to obtain an identity parameters. Current on bipolar current source output (point A) is equal to a difference of currents I_{s^+} and I_{s^-}. When they are equal the current through the resistor $R16$ does not flow. Zero potential sets on the output of Op Amp $DA3$. Sources of transistors are connected with virtual ground. The output voltage on $DA3$ is equal to null, so current does not flow through Rm. The output voltage on $DA3$ will increase with positive input signal (V_g) and the current will flow through Rm. The same current will be consumed on positive supply net of Op Amp $DA3$. The current of source $VT2a$ will decrease because of $I_{R16} = I_{S^+} + I_{Vdd\_DA3}$, where I_{Vdd_DA3} - current on positive supply net of Op Amp $DA3$. Voltage on the output of $DA3$ increases until current through Rm resistor does not become equal to current through $R15$ resistor.

Analogous processes occur when negative input signal (V_g) comes. Thus current negative feedback is provided. The output current (I_{out}) of voltage to current converter is completely defined by current of resistor $R15$ and does not depend on resistance Rm. It is equal to $I_{out} = V_g / R15$ if Op Amp is operated in linear (not saturated) mode. The direct component of output current will be equal to null if currents through resistors $R16$ and $R17$ are equal. It can be obtained by accurate adjustment of resistors or added direct current compensation unit. We chose the second variant - an integrator on Op Amp $DA2.B$. Its output voltage is formed proportionally to integral from an input current. This voltage sets an additional direct current which is summed with the current I_{s^-} and the difference of transistors direct currents is compensated. The constant of integration is calculated much more than the maximum period of input signal oscillations.

Instrumentation amplifier with DC compensation unit

Instrumental amplifier (IA) is chosen as a single integrated circuit INA128e (**Fig.6**). The alternative voltage gained in 3 times with direct component is supplied to input of compensation unit from output of IA (**Fig.6**). It carries out removal of the undesirable direct component inherent in any of salt solution as it is established above. The principle of this unit working is the same as in VCV. Integrator on Op Amp $DA5.B$ is put At feedback of Op Amp $DA5.A$. Op Amp $DA5.A$ is a basis for the inverting amplifier design. Two constant voltages (one from integrator and another from IA) are supplied on inputs of Op Amp at direct currents mode as we can see. These signals are almost identical, they are subtracted and only alternative voltage (V_m) stays on output of IA.

Temperature correction unit

The temperature correction unit (**Fig.7**) was synthesized according to equation (1). The equation (1) for voltage takes the following form considering that the current is fixed $U(25^\circ C) = V_m \cdot [1 + 0,22 \cdot (U(t) - 25)]$, where $U(25^\circ C)$ - measured voltage after the temperature correction, the result is given on temperature of $25^\circ C$. $U(t)$ - equivalent voltage from the temperature sensor.

The signal $U(t)$ comes from temperature sensor LM35 and it is supplied to input of adder designed on OpAmp $DA7.A$. Nominal of resistors $R35 - R38$ were calculated to make simultaneously both operations - summation and multiplication on $0,22$. Thus $0,22 = R38 / R35$ and $R37 = R38 / (0,22 + 0,22 - 1)$. The voltage $-25mV$ is applied to another input of the adder. This voltage is formed from non-inverting amplifier designed on Op Amp $DA6.A$ with gain $K = -R32/R31$. Voltage from precision reference TL431 is set on input of this non-inverting amplifier, which gives a stable voltage of 2.5 V (in this inclusive circuit **Fig.7**) and has a low output resistance. The signal $0,22\cdot(t-25)$ is obtained from output of the adder and then it comes to input of next adder. The voltage of 1V is supplied to another input of this adder, it is formed by the voltage divider (resistors $R43$ and $R44$). The voltage from the same TL431 is supplied to the input of this voltage divider.

Nominal values of resistors $R39 - R42$ were calculated to obtain signal on adder output, which value is equal $[1+0,22\cdot(t-25)]$.

This signal comes to one of inputs of multiplier MPY634 and signal of V_m is supplied to another input. The transfer function of multiplier has operation of division on 10. Therefore, the non-inverting amplifier with gain in 10 times is set for its compensation at output of multiplier. It is also made because for these purposes it was not possible to involve SF input correctly. The signal of $U(25^{\circ}C)$ is obtained as a result on output of temperature correction unit.

Rectifier

Rectifier (**Fig.8**) transforms the alternating voltage V_0 into direct voltage V_d with conversion coefficient $Kd = 0.95$. Double NPN general purpose transistor ($VT3$) was applied instead of diodes to obtain more precision of Rectifier. Each of bipolar transistors is in inclusive in circuit as a diode.

Simulation unit

This circuit design (**Fig.9**) simulates change of voltage measured from a water food solution under the same dependence as in a real water food solution. It has been synthesized according to equation (2). Trimmer ($R59$) has a logarithmic dependence of resistance on a rotation angle. User can set value of resistance coincided with desirable estimation of salinity and concentration of salt changing its position. Next trimmer is a linear resistor $R56$. It allows setting a level of maximum point for measurements and, thus, choosing a desirable water food solution for salt addition. (**Table 1**)

Comparator with Control unit of batcher

Comparator was designed on LM311 (**Fig.10**). Signals are supplied to the inputs of comparator from output of rectifier (V_d) and from output of simulation unit **(V_i).** The comparator is locked if the level of voltage on its inverting input is equal or more than level on its non-inverting input. It supplies power to mechanism of the batcher (**Fig.11**) which adds a portion of salt into water food solution.

Until the salinity of water food solution does not achieve the certain level, salt pours out at water food solution. When desirable salinity is achieved, the salt adding is stopped.

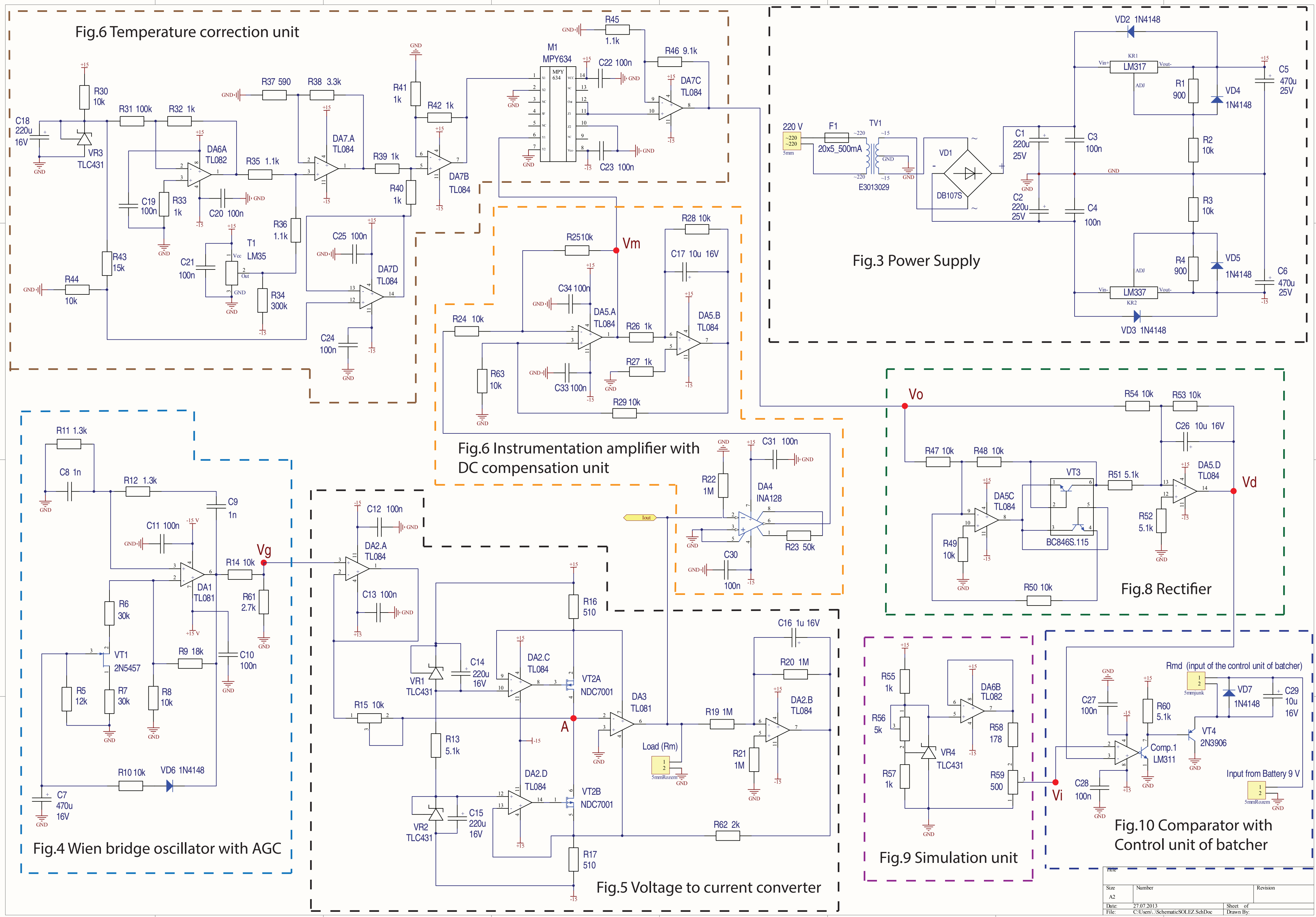

Fig.6 Temperature correction unit
Fig.3 Power Supply
Fig.6 Instrumentation amplifier with DC compensation unit
Fig.8 Rectifier
Fig.4 Wien bridge oscillator with AGC
Fig.5 Voltage to current converter
Fig.9 Simulation unit
Fig.10 Comparator with Control unit of batcher
Vm
Vo
Vd
Vg
A
Vi
M1 MPY634
DA7C TL084
DA7B TL084
DA7.A TL084
DA7D TL084
DA6A TL082
T1 LM35
VR3 TLC431
DA5.A TL084
DA5.B TL084
DA4 INA128
DA5C TL084
DA5.D TL084
VT3 BC846S.115
DA1 TL081
VT1 2N5457
DA2.A TL084
DA2.B TL084
DA2.C TL084
DA2.D TL084
DA3 TL081
VT2A NDC7001
VT2B NDC7001
VR1 TLC431
VR2 TLC431
Load (Rm)
DA6B TL082
VR4 TLC431
Comp.1 LM311
VT4 2N3906
VD7 1N4148
Rmd (input of the control unit of batcher)
Input from Battery 9 V
220 V
F1 20x5_500mA
TV1 E3013029
VD1 DB107S
KR1 LM317
KR2 LM337
VD2 1N4148
VD3 1N4148
VD4 1N4148
VD5 1N4148
VD6 1N4148
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Conclusions and Summary

We have developed the device for automatic salt addition in water food solutions. Work of all circuits was simulated in TINA Design Suite. Also, we have created an efficient breadboard (**Fig.12, Fig.13**). This device is intended to:

- ✓ Process automation of salting water food solution, what is actual in cookery;
- ✓ Preparation automations of physiological solution (NaCl), actual in medicine.

This device is capable to obtain accuracy of resistance measurement with error less than 1 %. Due to this, a high reliability of a salinity estimation of salt solution is obtained when it is prepared. Also, it is possible to define concentration of NaCl in any solution with high accuracy. On the basis of this device, it is possibly to modernize lines and processes of various solutions preparation.

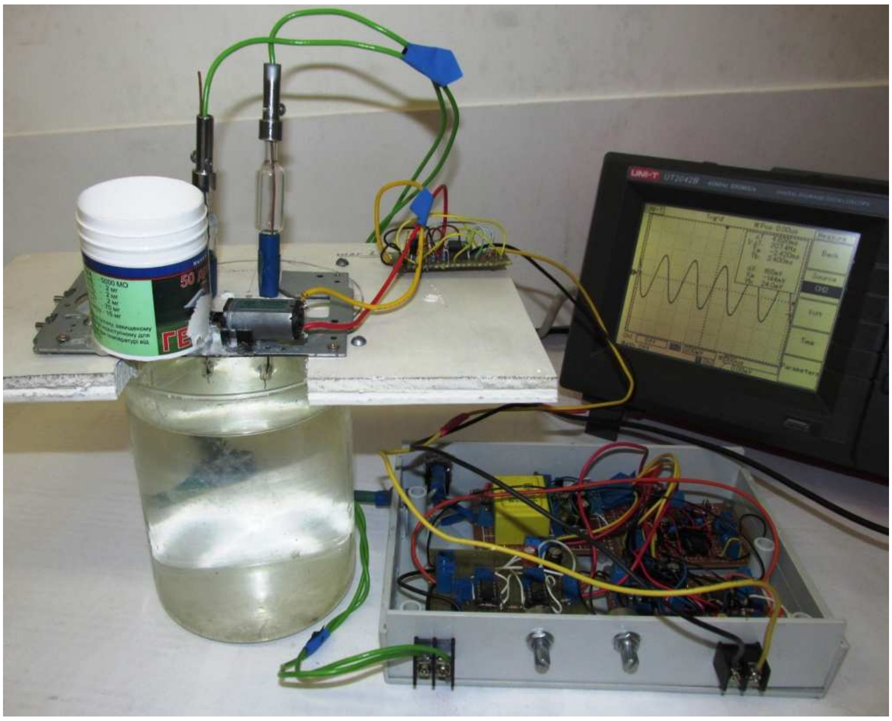

Fig.12 The first prototype of the device

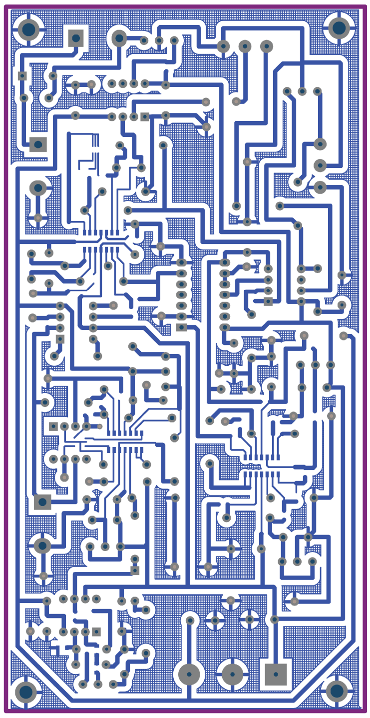

Fig.13 The breadboard of a next prototype

Future plans

- ➢ We will make the indication of salinity estimation level, chosen by a user (Q = 0 - 10 mark), for example, by means of LM3914 from Texas Instruments. It is a simple, low-cost and fail-safe decision for this aim;
- ➢ We want to show information about concentration of salt on LCD screen;
- ➢ We plan to place calibrated scales around of resistors $R58$ and $R60$ during more careful constructional design. It will be numerical scale of salinity estimation for $R60$ and scale of different types of water food solutions for $R58$.
- ➢ The breadboard of the following prototypes will have small size and sophisticated form, because it will be placed directly on a pot or on a spoon, which can be used as one of electrodes and will increase the comfort of using.

It is possible to automate a metering-in of other granular substances to conduct additional experimental researches.