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THE TRANSITION PERIOD OF THE CHARGING OF ACCUMULATORS

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Abstract: **The states of electrochemical phenomena in the accumulators are passing through several phases between the moment of commutation and the permanent period of charging. These successive states appear once at every commutation. This transitory period is lasting approximately 1 millisecond in the case of lead-acid accumulators.**

Keywords: *transition period, charging of accumulators, Lead-Acid-Battery*

I. INTRODUCTION

What's happening to the accumulators' electrods when the charger is coupled? The advantage of charging with impulses is just in connection with the desulphation phenomen? Knowing the complexity of electrochimical reactions in the accumulators, a specifical transition process from the equilibrium state to the charging state must exist.

The study of charging with impulses [1], [2] shows advantages of these types in contrast to classical charging techniques [3]. Adding the control of charging depending on the state of the accumulator [4], we obtain a charging which is independent from destructives factors and which is protected.

Applying the Zero-Current-Switching tehnique [5], the high efficiency of fast switching in chargers from the equilibrum state to the charging state is demonstrated. Most important is the battery state-of-charge analysis [6] and the multi-state algorithm [7] in our research.

This article is trying to present the results of measurements of electrical parameters in the switching period. The measurement of parameters and the command of generating impulses is realized by a microcontroller-commanded device, which is transmitting these data to a computer for analysis and projection.

II. THEORETICAL GROUNDS

The charging of the accumulators has on its basis chemical reactions that are in contradiction with those of discharging ones. The reaction mechanism is unfolding in the following way: the primary components are led into the reaction zone (nearby the surface of the electrodes in the electrolyte), there the reaction takes place and the resulting components are led outside the zone to assure the following components' reactions.

The transport of the components in the electrolyte and the proper reaction need each a distinct and different period of time. In the permanent system of charging these different periods can`t be identified, because in every moment millions of reactions are taking place on a unitary surface, each having different phases which are overlapping one another. As a result, the whole process is seen as a continuous phenomenon.

At a certain moment, in the state of equilibrium, when the accumulator is not charging or discharging, certain reactions are taking place in both senses, only their results are the same ones and they are produced in the reaction zone, but without the transport of the components.

In time, the state of equilibrium changes into the discharging state of the accumulator and this phenomenon is called auto-discharging.

In the moment of transition from the state of equilibrium to the process of charging, we can identify the following distinct phases, through which the transportation of the particles into the reaction zone is triggered:

- the electrical field of the charger's source gets to the reaction zone with a propagation speed approaching the light speed
- on the electrically charged particles (positive and negative ions, electrons) a Coulombian force will be driven due to the electrical field which was created
- the period of inertness depends on the mass of the particles and this is the period of time between the appearance of the electrical field and the moment in which the particle starts its movement under this field`s effect
- the acceleration period is the period of time between the moment in which the particle starts its movement under the influence of the electrical field and the time of reaching its relative maximum speed under the influence of the field
- the period of continuous transportation is the period of time in which the particle is moving with relative maximum speed until the reaction zone. This period was study sufficiently.

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III. THE INVESTIGATION DEVICE

The device used for the study of the transition period has the following characteristics:

- the measurement of the voltage at the accumulator`s terminals with the resolution of 12 bits in the interval of 10.5-13.5 V
- the measurement of the current through the circuit with the resolution of 12 bits in the interval of +/- 1A
- the measurement of the voltage and of the current at the interval of 250 microseconds
- the moment of commutation of the charger`s source at the accumulator`s terminals and the interval of measurement are programmable
- the transmission of the measured parameters to a computer through a USB port

IV. FUNCTION OF THE DEVICE

The central unit of command is realized by a STM32F429ZI microcontroller, implemented on a Discovery kit board, which is endowed with communication interfaces, LCD touchscreen and input-output channels. The peripheral device connected to the microcontroller is propagating and amplifying the command of the impulse and it is transforming the measured parameters (figure 1).

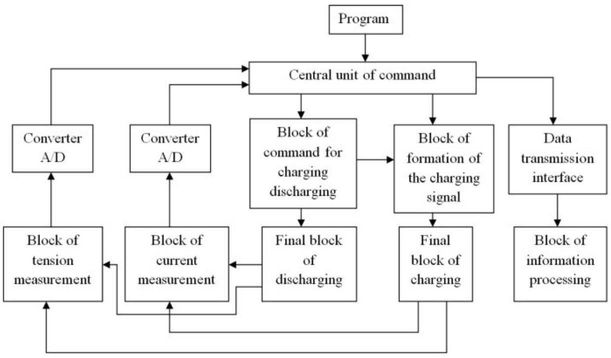

Figure 1. The block scheme of the device

The presented circuit scheme (figure 10) can assure both the charging and the discharging of the accumulator through the DCH (discharge) signal received from the microcontroller. Both in the absence of the entering signal and of the low input, the level of 0 volt is assured the input of mosfet driver U2 (TC4420), connected to ground by a 10k resistance. In this case, we obtain at output a 0 voltage level and the relay RS-12 is in starting position.

Thus the accumulator will discharge through a 15ohm/15w resistance which assures a discharging current of approximately 0,8A (depending on the state of charge). To this electric circuit is also connected in series a current sensor of type CSLW6B1 which is working in the interval of +/-1A (the interval 0-1A being for charging and the interval -1-0A being for discharging). A high level DCH input signal received from the microcontroller to the input of the MOS driver will assure at the output a voltage close to the supplying voltage of +15,5V. This voltage level through the 240 ohm resistance is supplying the RS-12 relay, which will switch its 2 commutators and through this the 15,5V of the supplying source will be directly connected at the positive electrode.

The negative electrode will be connected to the ground by a current sensor, a 5,6 ohm resistance and the drain-source of the N-MOSFET transistor. If the N-MOSFET transistor is opened, we get charging and if not, we have pause (the accumulator is not charging or discharging).

The power-mosfet AP20T03GJ-HF-3TB is commanded by the U1 (TC4420) mosfet driver, its gate being connected to the output of the driver, which receives at input a command signal from the microcontroller. This input in the absence of the command signal has a high level assured by a 10k resistance which is connected to a 5V supply.

The mosfet drivers and the N-MOSFET transistors can work at commutation frequencies of tenths of MHz. In case of charging the periodical interruption of the circuit can be commanded by the microcontroller and through this a rectangular signal and impulses can be obtained.

The 4,7uF and 100nF capacitors coupled in parallel to the alimentation of the mosfet drivers assure a stability of functioning by filtering the high frequency components existing at the alimentation, these components resulting from the switchings. Likewise at the output of the drivers we have 2,2pF filtering capacitors for the stability of output signal. The 5,6 ohm resistance in series with the charging circuit assures a limitation of the maximum current.

The other ending of the circuit is that of collecting the voltage at the terminals and of the current through the accumulator which is converted in an adequate signal at the input of the microcontroller. This is realized by a instrumental amplifiers (LM324 which has integrated 4 operational amplifiers in the same capsule) for assuring stability and precision at the measurements.

The LM385 circuit, the 68k, 18k, 200k resistances and the 200k trimmer assure a precise voltage reference of 1,5V. These are calibrated with the help of the trimmer and of a high precision measuring instrument. This reference voltage is passed through the U3B repeater to assure a stability of its output due to the high resistance at the input. This reference voltage is introduced in the differential amplifier U3C at its inverting input.

The CSLW6B1 current sensor is supplied at the secondary part by 5V voltage and it is presenting at the output a level of voltage proportional to the current passing through the sensor between 1,5 and 3,5V (the output of the sensor having 2,5V level for the 0V input). This voltage at the output of the sensor is passed into the input of the U3A repeater. The 1Mohm resistors in the input of the U3A are connected to ground and they assure a higher impedance in the input.

The output of the repeater is connected to the non-inverting input of the differential amplifier U3C. This differential amplifier will compare this voltage level with the voltage reference and it will assure at the output the voltage level equal with the difference between the non-inverting and the inverting inputs. The level of voltage in the output of the differential amplifier is between 0-3V intervals and is proportional with the input current.

Therefore, the group of the 22kohm/0,1% precision resistances and the 50kohm trimmer assures approximately 1,5 multiplicity of the input differential voltage. The potential of both electrodes from the accumulator passes to input towards two different repeaters (U4A and U4B) for assuring high impedance into inputs, together with the 22kohm and 1Mohm resistances. These outputs pass to the inputs of the U4C differential amplifier (from the positive electrode to the non-inverting input and the negative electrode to the inverting input).

The U4C differential amplifier will have at the output exactly the difference of the positive and negative electrode in the accumulator. This value of voltage level passes to the non-inverted input of the U4D operational amplifier. To the inverted input of U4D, we connect a stable reference voltage level which has the precise value of 10,5V. This reference voltage level was assured by the U3D repeater, who has at the input a voltage reference of 10,5V produced by the TL431 integrate circuit, and the 10kohm, 2,2kohm and 50kohm trimmer. The precision value will be obtained from the change of the trimmer`s position.

According to my decision, the voltage level domain of the accumulators is satisfactory between 10,5 and 13,5V, thus we obtain at the output a voltage level domain between 0 and 3V, which the ADC (analog-digital converter) needs inside the microcontroller, and this domain corresponds with the voltage level between 10,5V and 13,5V. So we have a maximum precision in this domain.

The command of the discharge (DCH) signal was assured by the PC11 output ports and the CH (charging) signal was assured by the PB4 output port from the microcontroller. The analogical signal which corresponds to the differential voltage level from the accumulator passes to the PA5 input port of the microcontroller. Inside this port there is an analog-digital converter.

The analogical signal from the current measurement passes from the charging/discharging circuit to the PC3 input port of the microcontroller. Inside this port there is another analog-digital converter.

The measured value of the electrical parameters will be transmitted to SDRAM memory and from there it will be transmitted by the PA9 output port to the USB interface circuit. From this interface the data will pass to an external computer and it will be saved in text files for more processing.

The TTL-232R-3V3-WE presented stability among the USB interface circuits.

The peripheral device (figure 2) was produced in classical mode.

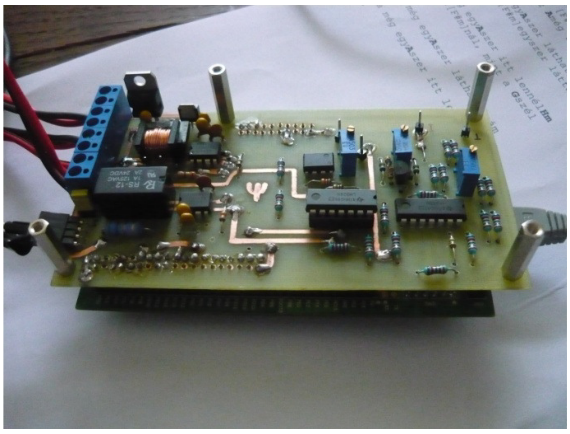

Figure 2. The peripheral face of the device

V. THE METHOD OF REALIZING THE EXPERIMENTS

The software (figure 3) for programming the microcontroller is writing in C language in the evaluation version of the MicroVision 5 Development Kit.

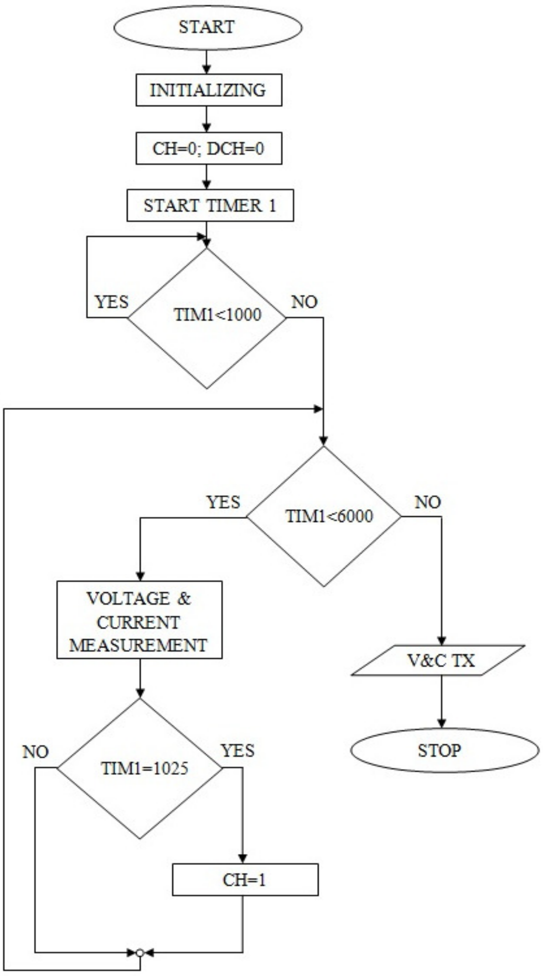

Figure 3. The algorithm of the software

The microcontroller was programmed to capture the electrical parameter (voltage and current) in 6 seconds. In the first second the measurement will start without charging the accumulator. This period is necessary to stabilize the measurement process. Afterwards, the transmission of data to the computer will start and after 25 ms the charger is switching. The parameters are transmitted and in the following 5 seconds they are saved and after that the measurement and the charging will stop.

Both measurements (the voltage value and the current value) are collected in every 250 microseconds. These values are written in the buffer of the SDRAM memory inside the Discovery board for fast measurements. From there, the data will be transmitted by the USB interface to the external computer.

Through the putty.exe free software, the data will be received by a serial port at 115200bps speed, with setting the display at 40000 lines. So it will receive 20000 measurements of the voltage and of the current value directly from the ADC in separated lines. These values will be copied into the worksheet inside an excel file and the correspondent formulas will be applied for obtaining the real value of the voltage in volts (1) and the current in amperes (2).

$$\mathbf{U=U_{ADCV}*U_{ADC\text{-}MAX}/Nr+U_{REF}+U_{COR}\ (V)} \qquad (1)$$

where: - U_{ADCV} is the value of voltage from the ADC for voltage measurement

- $U_{ADC\text{-}MAX}$ =3V is the maximum value that can be applied into the input of the ADC

- Nr=4096 is the number of different values in the measured interval (the converter works with 12 bits)

- U_{REF} =10,65V is the value of the reference voltage

- U_{COR} =0,94V is the correction voltage for the charging mode (in discharge mode it doesn't exist)

$$\mathbf{I=(U_{ADCC}*U_{ADC\text{-}MAX}*100/(Nr-\ U_{REF}*100))*M\ (A)} \qquad (2)$$

where: - U_{ADCC} is the value of voltage from the ADC for current measurement

- $U_{ADC\text{-}MAX}$ =2,95V is the maximum value that can be applied into the input of the ADC

- Nr=4096 is the number of different values in the measured interval (the convertor works with 12 bits)

- U_{REF} =1,5V is the value of the reference voltage

- M=100/165 is the multiplicity factor in the final block of amplifiers for covering the domain.

These calculated values are the real values of measurement. These will be introduced in other cells and then we generate the necessary curves.

V. EXPERIMENTAL RESULTS

The circuit is programmed to capture these parameters for 6 seconds, in the first second the measurements start in a turned-on condition without being recorded, this time being necessary for the circuits of measurement to stabilize. Then the recording of time parameters starts for 25 seconds without the charging being connected. After this, the commutation to the charging condition is commanded and the parameters are being recorded for approximately 5 seconds, this time being enough for getting to a normal charging condition.

At the end of this period the charging is disconnected and the measurements are stopped. The measurements are being made in every 250 microseconds, the voltage (figure 4) and the current (figure 5) being measured as well.

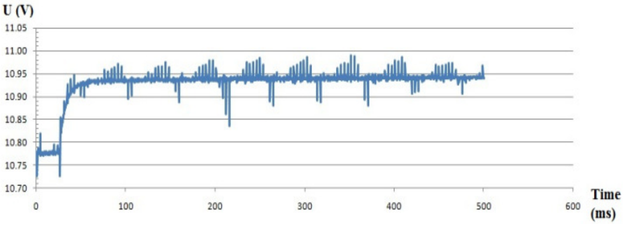

Figure 4. Voltages in the first 500 ms

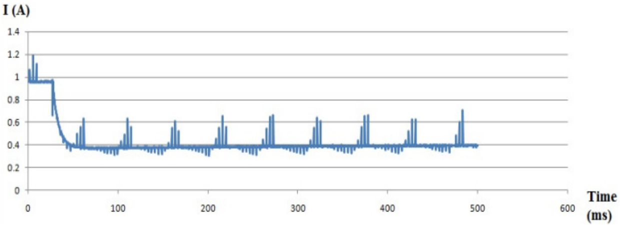

Figure 5. Current in the first 500 ms

From the graph the classic curves of charging the voltage and of the current can be recognized. The voltage grows abruptly from the moment of commutation, then a slow uniform growth can be observed, starting from approximately 50 ms which corresponds to the permanent system. In the case of the current, an abrupt reduction can be observed until the charging value of the permanent system and from that moment the current remains constant.

Increasing to maximum the commutation zone in the time interval between 25.5-28,5 ms and superposing the results of 10 different measurements, we get the following voltage curves likely (figure 6-7).

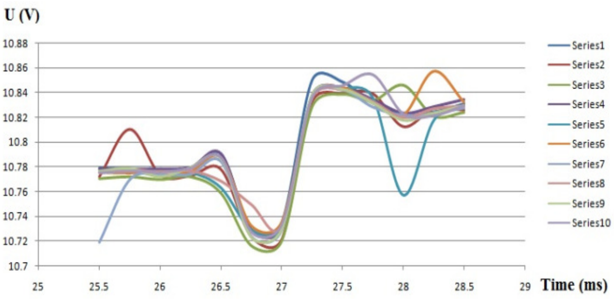

Figure 6. 10 different measurement of voltage in the time interval between 25,5-28,5 ms

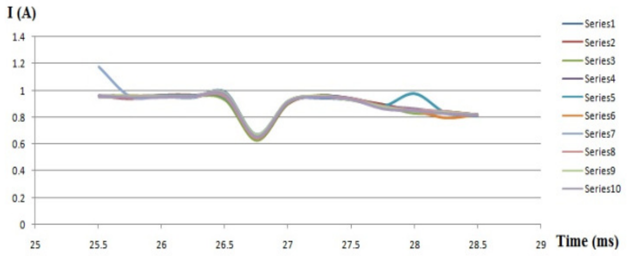

Figure 7. 10 different measurement of current in the time interval between 25,5-28,5 ms

We should also take into consideration the voltage curve obtained from the replacement of the accumulator with a 30 ohm resistance, to eliminate the case in which these curves are due to the self-adjustment of the source at the coupling of a charge (figure 8).

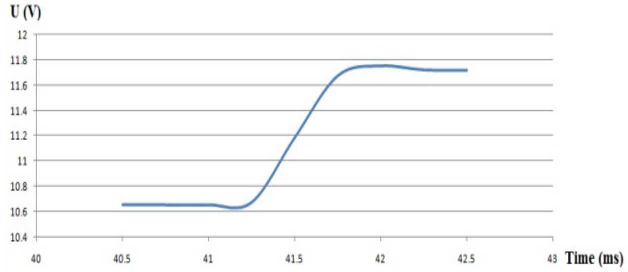

Figure 8. Voltage curve with resistance

At the end of the study of the signal`s form which appeared in the moment of commutation we have the following 8 phases (figure 9):

1. The phase before the commutation, which ends in the moment of the commutation.
2. The light increasing phase of the voltage and of the current.
3. The abrupt decreasing phase of the voltage and of the current.
4. The light increasing phase of the voltage and the abrupt phase of the current.
5. The abrupt increasing phase of the voltage and the light decreasing phase of the current.
6. The light decreasing phase of the voltage and the light decreasing phase of the current.
7. The abrupt decreasing phase of the voltage and the light decreasing phase of the current.
8. The permanent period of charging.

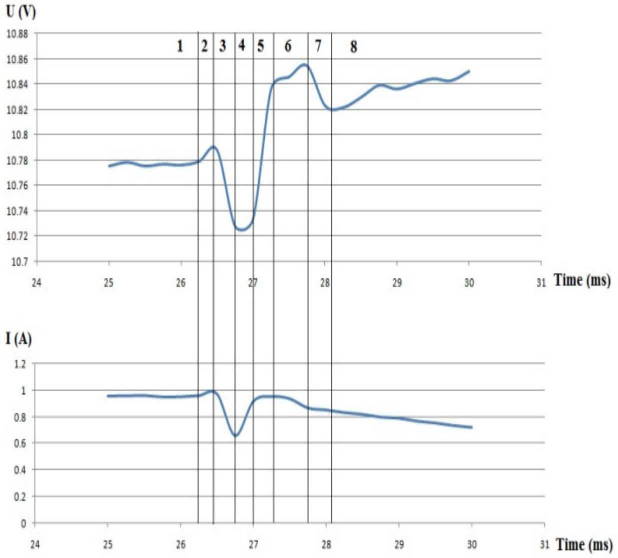

Figure 9. Different phases of the transition period

VI. CONCLUSION

From the experimental results the 8-phased signal was obtained, which frames into the transitional period of commuting the charger to the accumulator. In this approximate time of 1 millisecond we have a decreasing and an abrupt increasing phase of the voltage at the terminals and of the current through the circuit. In some phases we have even a shift of time between the two curves which indicates a capacitive aspect of these phases.

The results confirm the explanation of the phenomena from the reaction zone in the moment of the commutation of the charging voltage of the accumulators. These times can differ according to the construction and type of the accumulator, in our case the experiments were made by a Pb-acid accumulator of 12V/4.5 Ah.

This specific form of the 1 ms voltage and current at a commutation shows a perturbation of the accumulator`s equilibrium state. Before entering the charging phase we are confronting with a reaction of inertness from the part of the elements involved and there is an effort on their part to maintain the state of equilibrium opposing to the applied electrical field.

The study of this phenomenon would be welcomed through monitorizing several parameters in the reaction zone. With a special laboratory equipment, an impulse to a single accumulator cell is applied for monitorizing the speed of the particles, the temperature in the reaction zone, the speed of the basic and auxiliary electrochemical reactions, the density of the current, the electromagnetic field and other important parameters.

It is to be expected that in the case of a high voltage impulse, this signal with a specific form will appear much more pronounced. If so, it must be taken care of the fact that this impulse should be short enough for avoiding the deterioration of the accumulator.

The short charging impulse (with the duration comparable to this transition period) can be combined with a shorter negative impulse, in order to accelerate the inertness of the particles in the expected sense. Thus this phenomenon can be amplified and a synchronizing amoung the expected effect and the inertness of the particles can be reached. After the succession of such impulses a reduction of the invested energy would follow in the charging process, compared to the classical charging methods.

By using these results, the charging signals can be accorded with the impulses, the results leading to an increased efficiency of the accumulators` charging process.

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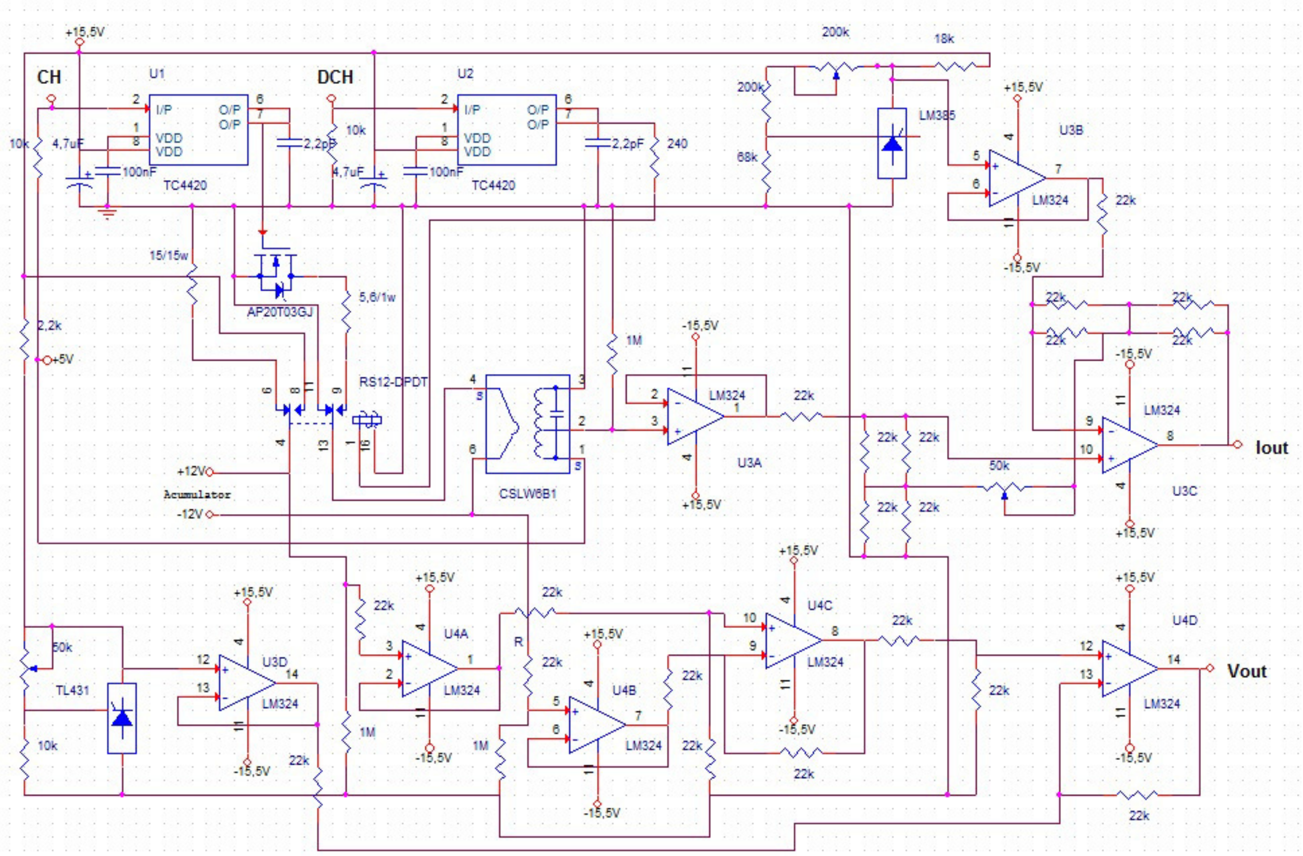

Figure 10. The electrical schematic of the peripheral circuit