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PAPER TYPE (Research paper)

Design and analysis of pulse oximetry circuits

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Abstract

This section should be the shortest part of the abstract and should very briefly outline the following information: 1-What is already known about the subject, related to the paper in question. 2- What is not known about the subject and hence what the study intended to examine (or what the paper seeks to present). One of the devices that is widely used in medicine is PULSE OXIMETRY. This device, which is used in most ICU wards (cardiac intensive care unit) and operating rooms of hospitals in the country, is a device that can be used to determine the percentage of oxygen saturation in human blood. What is stated in this report is the study of the theory and design of a pulse oximetry system, which acts based on a red and infrared light, is transmitted through the connection of a transducer to the human body tissue and the detection of light passing through the other side of the tissue. In this report, in the first chapter, the introduction and in the second chapter, the principles of pulse oximetry system theory are examined. In this chapter, with the help of photon diffusion theory in finger tissue find the relationship between the ratio of DC changes in light intensity received by the detector to AC changes in light intensity in both red and infrared types with a variety of absorption and dispersion coefficients, and then with the help of it, we get the system calibration table and curve. In the third chapter, the design and principles of structure and familiarity with different classes of pulse oximetry system are discussed. And in the fourth chapter, we present the results of testing the device on different people, including heart patients, and reviewing the error of the device and suggestions for completing the system.

Introduction

The use of electronic science in medicine began in the seventies and in recent years has made significant progress that has led to many changes in diagnosis and treatment. Imaging diagnostic systems such as radiology, ultrasound, CT scan, MRI, angiography and echocardiography make it possible to image all organs of the body. Therefore, that now specialists are able to see the inside of the human body with extraordinary clarity and quality with eyes that are equipped with the above systems and identify changes and deficiencies in them. For example, a device called a pacemaker regulates the heart rate of patients with slow rhythms. Another diagnostic system is the cardiac monitoring device, which is widely used in the CCU, ICU, and operating rooms. Cardiac monitoring devices make it possible to detect various physiological symptoms of the body, including signal, ECG, blood pressure, pulse oximetry, and so on. A pulse oximetry is a device that can be used to measure the percentage of oxygen saturation in human arterial blood. In some of them, the heart rate can also be determined. The American company Hewlett-Packard first made this device in 1970, which later became more complete. In more advanced models of this device, in addition to the percentage of blood oxygen saturation, the patient's ECG signal can be shown, as well as the pulse oximetry curve, which is similar to the human blood pressure curve. Today, this device is used daily in all operating rooms and intensive care units for all countries of the world. And is one of the most important factors in reducing mortality during anesthesia and endoscopy.

Introduction to the system structure

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Fig. (1) shows a set of different classes of designed pulse oximetry devices. As can be seen in the figure, in the power supply section, first the city electricity is converted to DC and after converting it to 22 volts, +9 volts and + 5 volts are made of it.

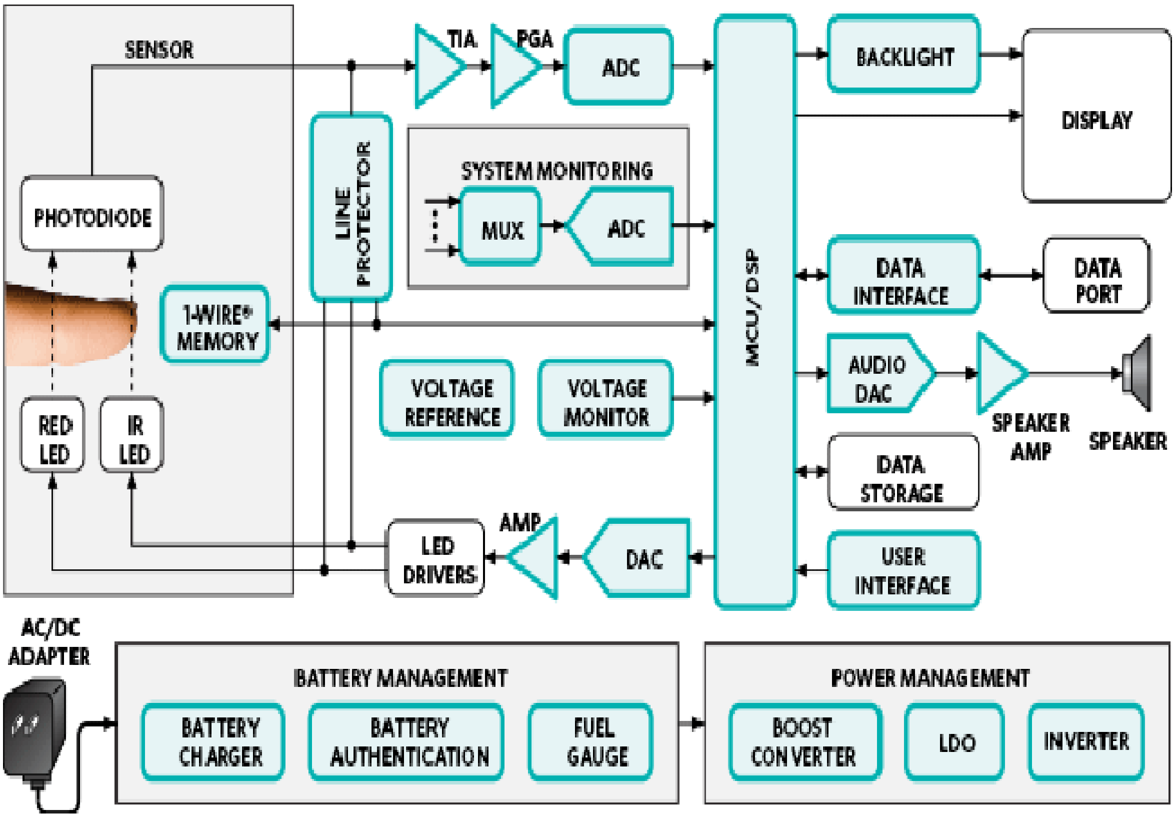

Fig. 1: Block diagram of pulse oximetry system

Voltages of 5 volts are used for all elements (transistors, buffers, logic gates) and operational amplifiers, and voltages of +9 volts are used only for seven-part displays with their actuators. The main part of the system, which is actually the heart of the pulse oximeter, is a microcontroller that its functions are:

1 - Send the start command to the transducer connected to the finger in a completely controlled and accurate way
2- Switch control to separate the signals generated by the detector
3- Processing of the resulting signals after filtering and amplification
4- Control the classes of seven-part displays and LCD monitors
5- Keys control for setting alarm limits to control minimum and maximum HR and SaO2
6- Command to turn off the power and the system

The general operation of the system is as follows:
By turning on the device, the microcontroller commands the light emitting diodes in a finger-shaped transducer to be excited according to a special algorithm. Simultaneously in the transducer detector, a current is generated in the transducer detector, which converts the current to voltage after passing through the filter, RF by the amplifier, instrumentation. Because the signal from the red and infrared light emits to the detector. By controlling the switch, the signals related to each light are separated, and after passing through the low-pass and high-pass filters located in each path, their DC and AC sections are separated. The DC part of each signal goes to the microcontroller and their AC part is applied to the microcontroller after filtering and re-amplifying.

Power supply for pulse oximetry device

Fig. (2) shows a view of the power supply of the pulse oximetry device. As shown in the figure, after applying city electricity to a 220V / 16V reducing transformer and rectifying its output, a DC voltage of 22 volts is generated.

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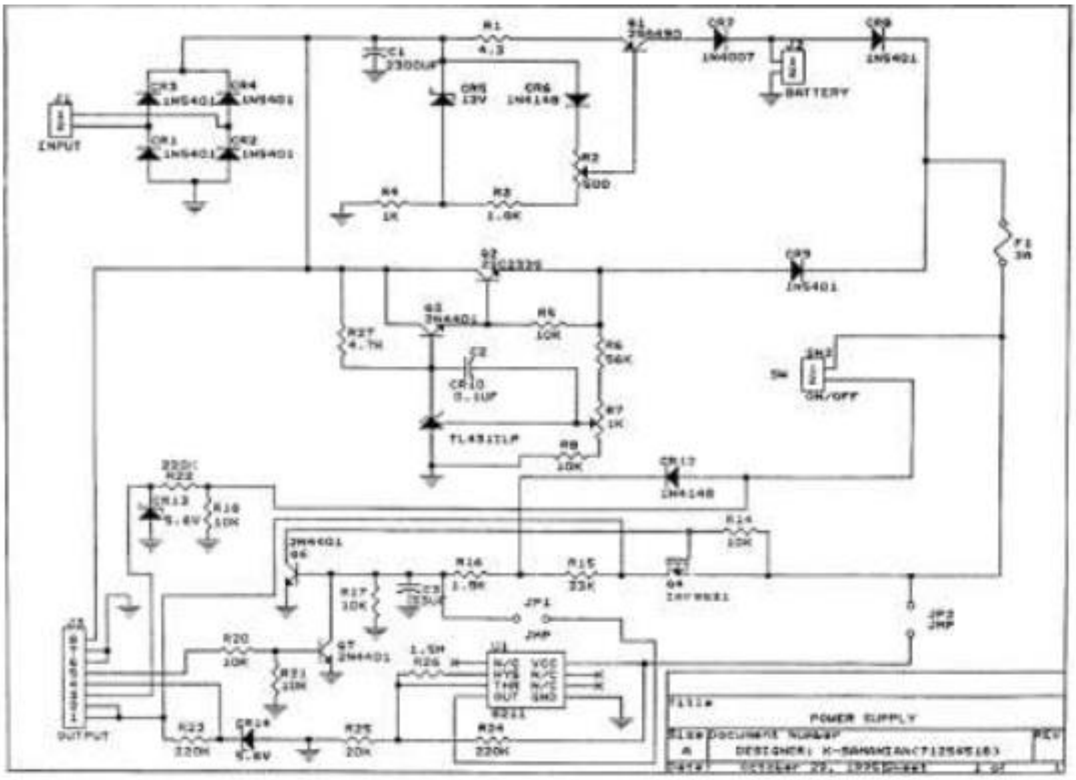

Fig. 2. Power supply of pulse oximetry device

This voltage is converted to a stabilized voltage of 15 volts with the help of transistors Q3, Q 2 and CR 10.

The CR10 is a precision voltage regulator with adjustable output that the middle end of it referred as a reference and its potential difference with respect to the anode point is 2.5 volts. By changing the middle head of R7 potentiometer, the emitter voltage of transistor Q2 can be changed from 2.15 volts to 75.16 volts. Transistor Q1 is used to charge the battery, so that in case of power outage, the battery connected to connector 12 can be used for the device. When the Sw key is pressed, the Q6 collector voltage becomes approximately 0.2 volts due to the Q6 transistor turning on in a short time. As a result, the voltage difference between the MOSFET source-gate Q4 exceeds its threshold voltage and the MOSFET turns on. The voltage on its source transferred to its drain with a slight drop when Q4 MOSFET turns on. Then it transmitted to pins 1 and 2 of connector 13 as the output voltage. MOSFET Q4 is a P-channel type that can tolerance current up to 10A and voltage VDS = 100V. If the SW key pressed again, CR13 Zener turns on for a short time and by connecting the Zener voltage to pin 13 of the U100 in the main circuit of the system, pin 15 of the microcontroller excited. By connecting it to pin 5 of J3 connector, transistor Q7 is turned on, and then the transistor is turned off. When Q is disconnected, the MOSFET transistor Q4 turned off and the 15 V voltage at pins 1 and 2 of connector 3 disconnected.

S was a controller chip, and when the 15V voltage in the power supply circuit reduced for some reason (especially when using Battery), this voltage drop reduces the voltage across pin 4 of the U, followed by disconnecting the MOSFET Q4. 2-amp FI fuse used to prevent the current passing through the circuit from increasing too much.

A. Create a voltage of +9 volts for seven-part displays

Because the seven-part displays in the device use high current, to reduce power dissipation and increase efficiency in the power supply of monitors, a switching voltage regulator used in the construction of +9 volts. Fig. (3) shows the switching voltage regulator circuit designed for the desired pulse oximetry device. In this circuit used TL494 switching IC ,which use PWM technique to control on and off Q1time transistor. This switching regulator designed in Step-Down mode and by the help of it from +15 volts made +9 volts. Due to this voltage conversion, the Duty Cycle of this regulator is about 60%.

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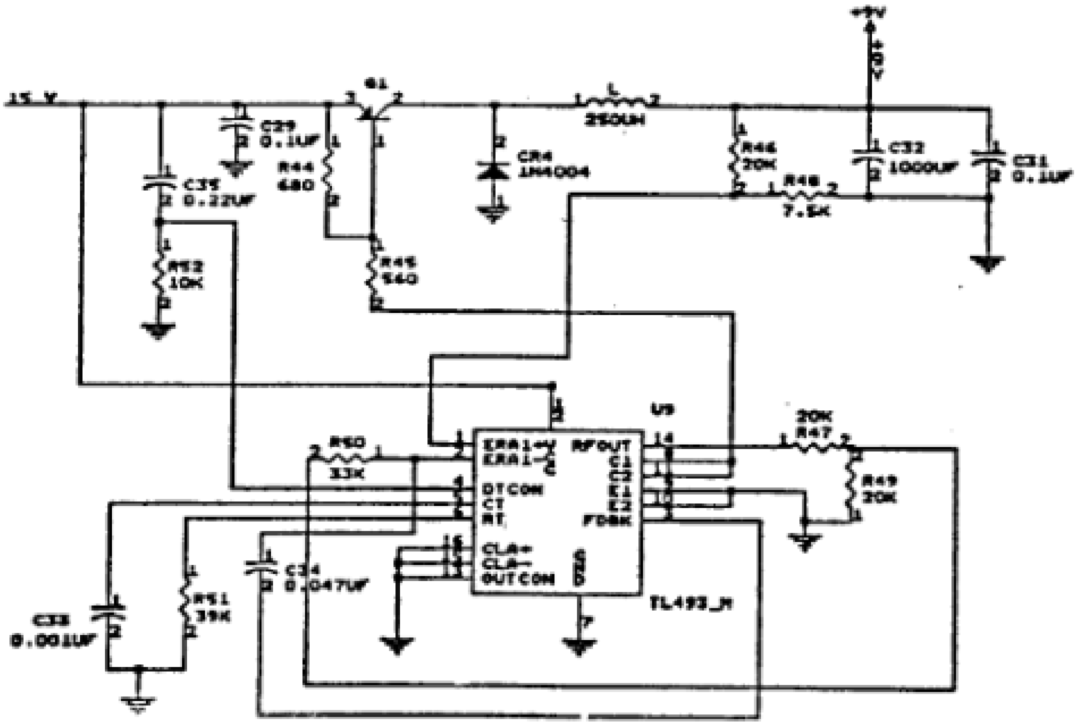

Fig. 3: Switching power supply for monitors

The value of inductor L is determined so that for the least contradiction of the inductor current, the following relation is established:

$$L \geq 3\frac{V_0}{I_0}.T.(1-\delta) \quad (1)$$

In the above relation, V0 is the output voltage, I0 is the output current, T is the switching frequency period and δ the value of the regulator Duty Cycle. If V0 is considered as 9 volts and I0 as 2 amps and 39 microseconds and δ 60% obtained minimum of 280 micro Henry. The value of T is determined by multiplying the value of C33 R51 by pins 6 and 5 of 9.

B. Create a -5 volts for operational amplifiers

Because to power the operational amplifiers used in the system requires a negative voltage and all powered with 5 volts, to create the voltage of -5 volts, a chip with the number ICL7660 is used, which is a voltage converter of CMOS type. Fig. 4 (U10) with capacitor C28 connected to pins 2 and 4 shows the 5V voltage output circuit.

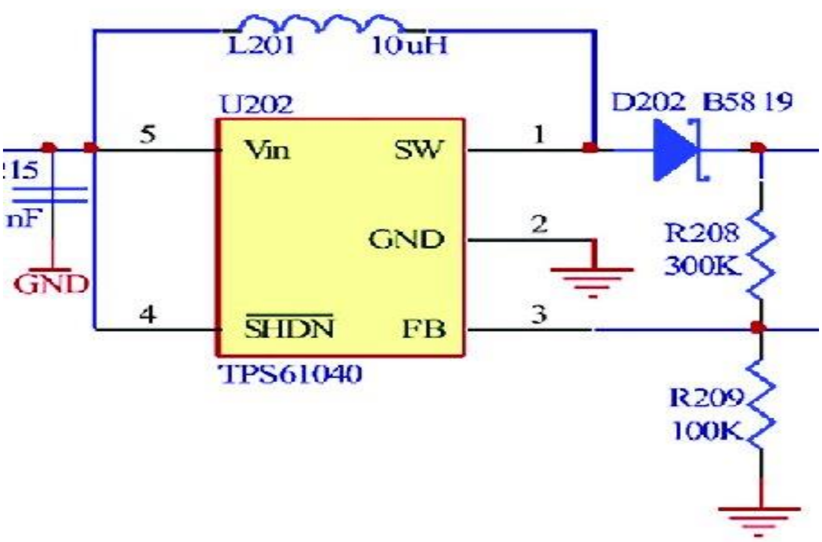

Fig. 4: power supply circuit from 5V

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The general specifications of this IC are the following features:

1- Voltage multiplier

2- Power efficiency up to 98%

3- Open circuit voltage conversion efficiency of 99.9%

4- Easy to use IC and need to connect two capacitors to its terminals

5- Input voltage range between 1.5 volts to 10 volts

C. Specifications of RF filter at detector output

To reduce the effect of noise caused by magnetic fields and high frequency waves in the detector medium in the transducer, especially the noise caused by the use of the electrocautery device used in the operating room, a low-pass RF filter used in the detector output. This filter, which is a passive type and is often known as an ESUR filter and designed as follows.

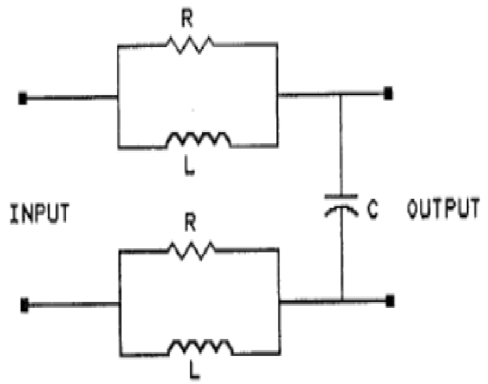

Fig. 5. RF filter for high frequency noise

According to Fig. (5), if the values of 150 micro Henry are considered to be 2.2 kΩ for R and 47 pF for capacitor C, the frequency response obtained from this filter has a bandwidth of -dB3 equal to 2 MHz. This bandwidth is intended for this reason, because with the help of this filter, the noise caused by high frequency waves in the environment that are around 10MHz to 15MHz can be easily removed.

Amplifier Instrumentation

Due to the small current in the detector output and the sensitivity of the detector to the input resistance connected to it, a current-to-voltage converter is used in the detector output. If we consider a typical differential amplifier as follows:

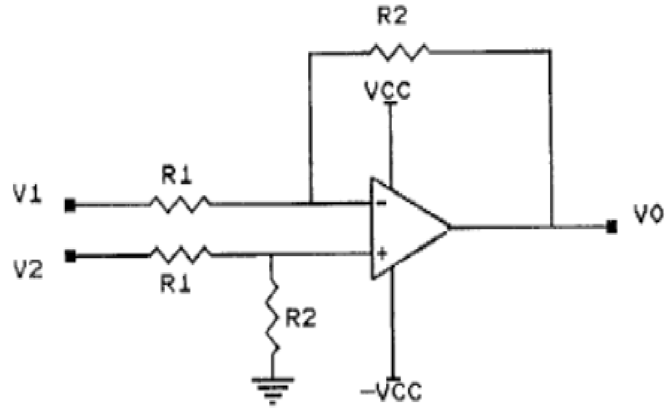

Fig. 6. Simple differential amplifier

The output value of V0 obtained as follows:

$$V_0 = (V_2 - V_1)\frac{R_2}{R_1} \tag{2}$$

Due to the above relationship and the ideality of the operational amplifier, it can be seen that the common mode gain (CMG) of the amplifier is zero and the gain of the differential mode (DMG) of the amplifier is R2 / R1. However, the ideal state does not occur, and there is little value for CMG due to the voltages and offset currents for Op Amp. Therefore, the criteria called Common Mode (CMRR) removal ratio for Op Amp defined as follows:

$$CMRR = \frac{DMG}{CMG} \tag{3}$$

The smaller the CMG, the larger the CMRR value and the closer the amplifier is to the ideal state. However, the simple differential amplifier (Fig. 6) has its disadvantages, including its low input resistance. This creates problems with the use of low-resistance sources. To solve this problem, the Instrumentation amplifier used according to Fig. 7. If we write the current and voltage equations for Fig. 7, the following equation obtained.

$$V_0 = (V_2 - V_1)\frac{R_2}{R_1}.\frac{2R_4 + R_3}{R_3} \tag{4}$$

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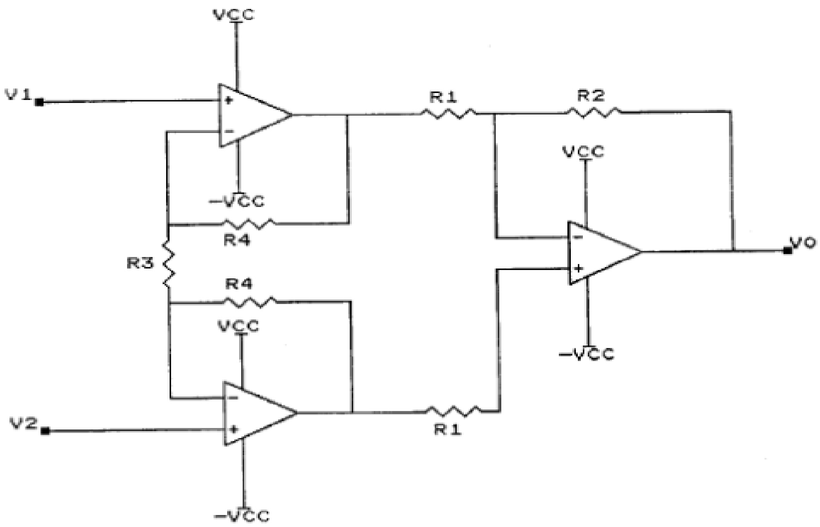

Fig. 7: Instrumentation Amplifier

Also due to the same amount of CMG for A1, A2 and DMG:

$$DMG = \frac{2R_4 + R_3}{R_3} \quad (5)$$

It can be said that the amplifier CMRR only depends on its DMG level. An Instrumentation amplifier has features such as:

1- High input resistance
2- High CMRR
3- Low output resistance
4- Low dc offset

But one of the most important characteristics of this type of amplifier, which widely used in industry is deleting the signal with a frequency of 50 Hz at the output. If the city power supply, which has a frequency of 50 Hz, interferes with the input signal for any reason, due to the effect of removing the common mode by the amplifier, a signal with a frequency of 50 Hz does not appear at the output. These amplifiers with the above specifications usually used in the output of industrial transducers. Fig. 8 shows the use of this type of amplifier, which is otherwise located in the transducer detector output of the pulse oximeter.

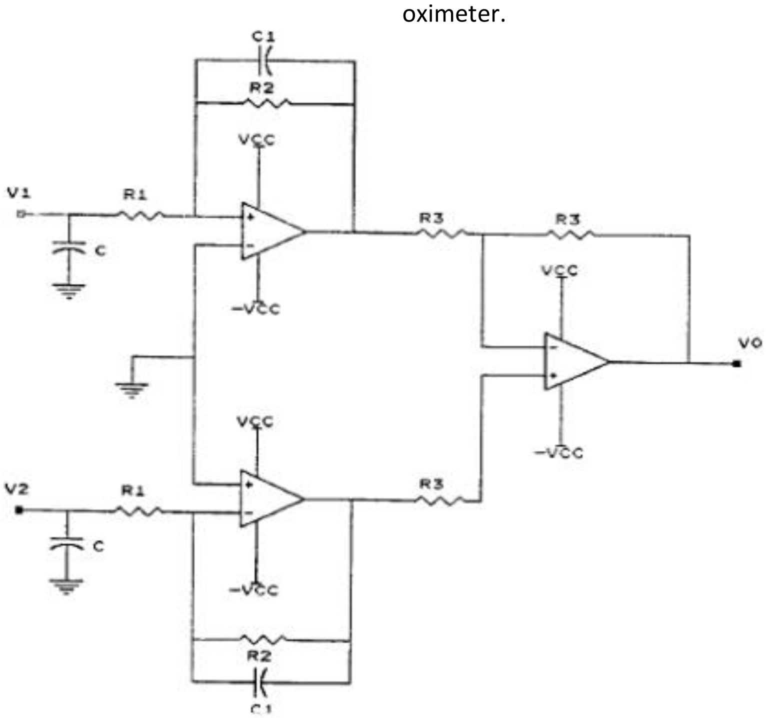

Fig. 8: Instrumentation amplifier at the transducer detector output

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Operational amplifiers A2, A1, in addition to amplifying properties due to the presence of capacitors C1 and C2 on their feedback resistors, also filter and remove some annoying frequencies. A3 differential amplifier has a differential gain of 5 and in total, the amount of differential gain of the amplifier (A3, A2, A1) instrumentation is absolutely equal to 10. Usually the gain of A1 and A2 amplifiers is considered small. Saturation for output may occur due to the use of high offset Op Amps. The Op used in this amplifier is the chip number LT 1014 from Linear Technology factory, which itself includes 4 independent Op Amps. The main specifications of this type of Op Amp, known as precision operational amplifier, are as follows:

1- Input offset voltage, maximum 150 7 at 25 °

2-The thermal coefficient voltage is at least $2\mu V / C^{o}$

3- Input offset current, maximum 0.8nA at 25 °

4-Open circuit gain in size 1.5×10^{6} with $R_L = 600\Omega$

5- Very low power supply, Maximum 0.5mA at 25 °

6-Peak-to-peak noise voltage is very low in size $0.55\mu m$

7- Very low current flow size $0.07\, PA/\sqrt{HZ}$

Low and high-pass filters

After using the S switch, which used to separate the signals from red and infrared light, active and passive low-pass and high-pass filters used to separate the DC and AC part of each signal. Fig. (9) shows the active low-pass filters used at switch S output to separate the DC portion of the signal.

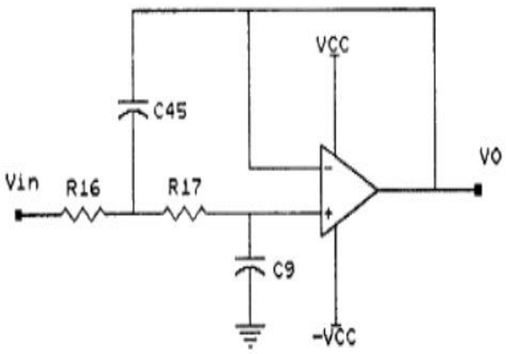

Fig. 9: Active low pass filter

As shown in the figure, this capacitor uses two capacitors C9 and C45. These two capacitors cause the filter to be read a second time. The gain of this filter is one and its cut-off frequency -dB3 obtained from the following approximate relation:

$$f_{-3db} \frac{1}{2\pi}\sqrt{\frac{1}{R_{16}R_{17}C_9C_{45}}} \qquad (6)$$

According to the values in the figure, for capacitors and resistors, the filter cut-off frequency is 7.74Hz. As can be seen, this cut-off frequency is very low because the main frequency of the output signal from switch S is about 2Hz. It noted that the output of each of these active low-pass filters first applied to an RC low-pass filter and then the output of this filter enters the microcontroller. Also, the overpass filters that are used in the circuit to separate the AC part of the signal are as follows.

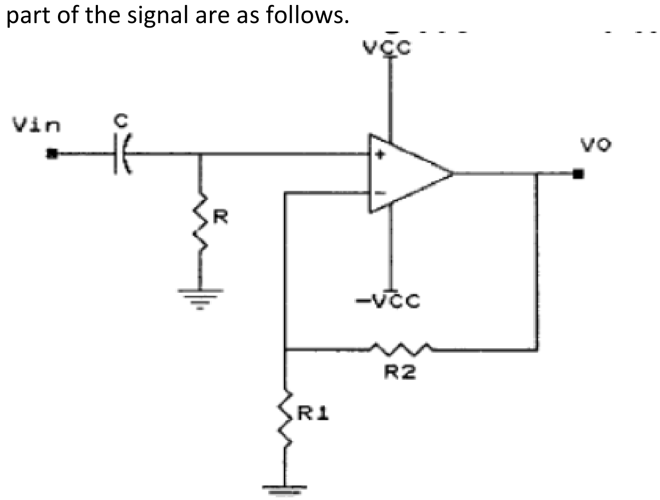

Fig. 10: Active high-pass filter

As shown in the figure above, an RC used at the positive OpAmp input, and at the resistor, negative feedback connected to the output and the negative OpAmp. Bandwidth -dB3 for this high-pass active filter with a gain of 54.3 obtained at 0.53Hz according to the values of R and C.

Red and infrared diode switch circuit in the transducer

The transducer of the device, in the light-to-finger radiation section, consists of two red and infrared diodes, from which light radiation done in three specific time phases. If we divide the time T into three parts A and a and b:

1- At time t1 only the red light diode is on

2- At time t2 only the infrared light diode is on

3-They turn off in time with both red and infrared light emitting diodes.

This time interval intended as a time delay until the next start-up, as well as to eliminate the current generated by ambient light in the transducer detector. The switch

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circuit of the red and infrared transducer diode drivers is as shown in Fig. 11.

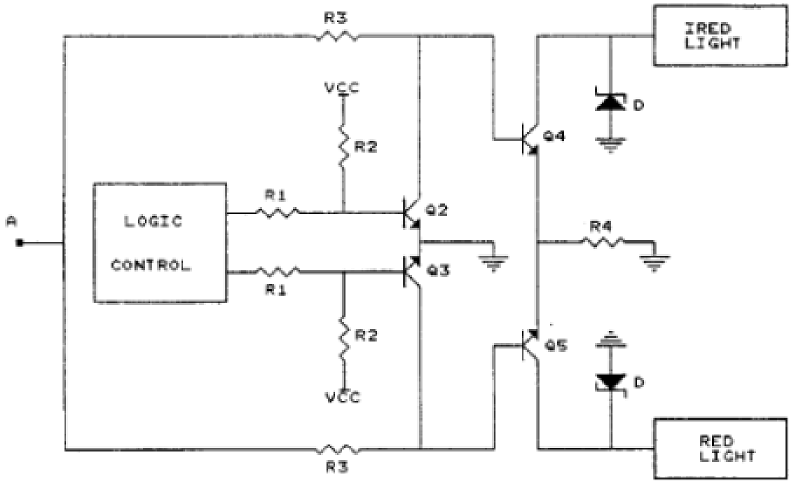

Fig. 11: Diode driver switching circuit

According to the values of dc voltage at the point, A at or when Q2 is on and Q3 is off. Due to the status of Q 2 and Q3, transistors turn off and Q5 turn on, if the Q5 is a red LED and the Q4 is an infrared LED, and then the red LED is on. The reverse of the above states for an infrared light emitting diode occurs in time. Also if in time, both transistors Q2 and Q3 turn on, then Q4 and Q5 are both off, and this is when the detector circuit uses the switch (U2) S at the output of the amplifier (U1) Instrumentation to remove the signal detected by ambient light. The switching signal frequency of the starting transistors is around 600 Hz with a 30% duty cycle. The amount of switching frequency calculated according to the patient's heart rate (HR) or in other words, the period of the blood flow pulse. To separate the amplified signal at the detector output in relation to any light emitted by the finger and apply it to the LPF and HPF filters from a chip numbered 4053 U2, which is an analog multiplexer and used as switch S. Fig. 12 shows a view of this IC with the names of its bases.

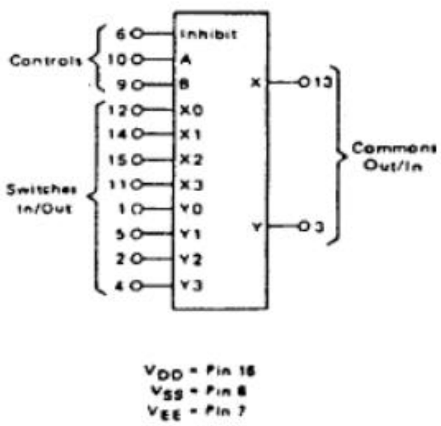

Fig. 12: Chip 4053

When controller 8 is active, input U2 transferred to output X1, and this is exactly when the red light diode turns on. When control base B activated from U2, input X transmitted to output Y, and this is when the detected signal related to infrared light. When both diodes are off, the output base of Z1 activated from U2. Then when activated, the RC high-pass filter enters the circuit in the U7A amplifier input and removes the DC signal generated by the ambient light. The signal base of time control A, B and C done through the output of the microcontroller by a logic circuit.

Using D / A converter to convert information and control interest

A D / A converter used to control the light intensity of the diodes inside the transducer. This converter receives digital information from the microcontroller and the memory used next to it. By converting it to an analog voltage value, it determines the current passing through transistors A4 and Q5. Another D / A converter used as an automatic gain controller that operates digitally. The chip used in the D / A converter part of this system is AD7628 from Analog Devices Company. The chip is powered by 5 volts and consists of two separate DAC. The following figure shows the structure of the chip along with a diagram of its control signals.

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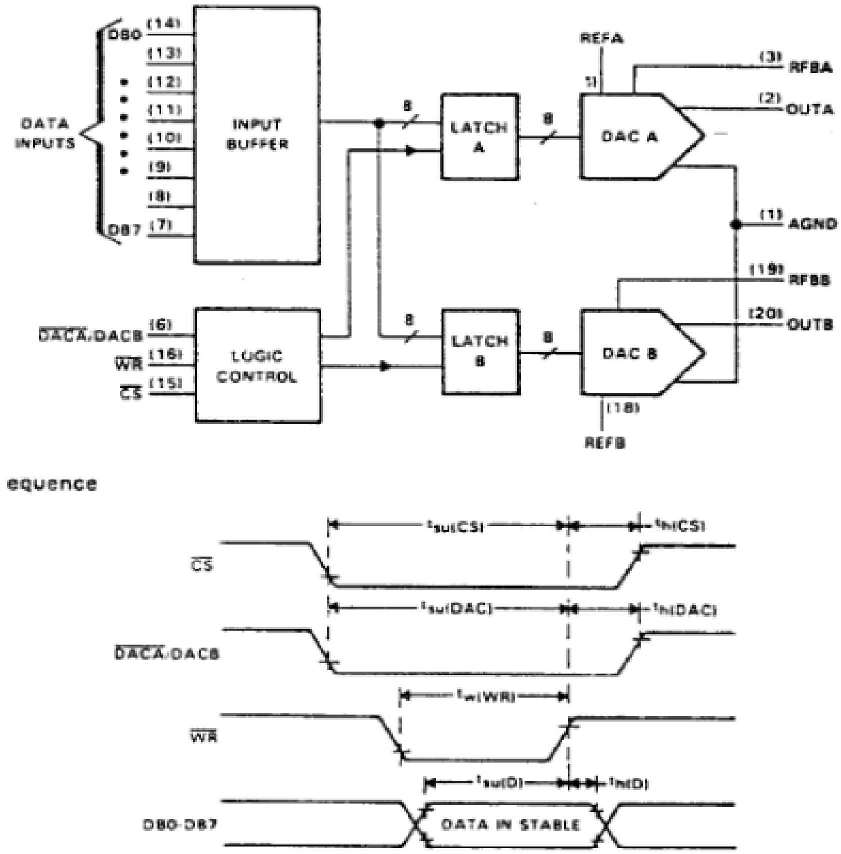

Fig. 13: AD7628 chip structure with its control signals

As shown in the figure above, this chip has an input buffer that can be used for DACA and DACB. When the CS base of the chip is Low, the chip is in a state that used .Now if the DA CA / DAB base is in Low mode, the digital data entered into converter A, and if this base is in the high state, the information enters the converter B. These converters perform digital to analog conversion according to the law of consecutive approximations. After selecting one of the two types of DACA or DACB, by activating the WR base in Low mode, the digital information applied to the chip obtained analog to the output. One of the advantages of the latch class for both parts is the DAC storage of information at the source output. The table below shows the selection of different operating modes on this chip.

Table 1. Operational selection in chip 7

DA CA/ DACB	CS	WR	DACA	DACB
L	L	L	Write	Hold
H	L	L	Hold	Write
X	H	X	Hold	Hold
X	X	H	Hold	Hold

This chip used in both unipolar and bipolar converters. In the chip's unipolar converter, by giving eight-bit digital information from zero to 255, the analog output voltage obtained from zero to values but $-\frac{255}{256}V_{ref}$ in its bipolar type, the value of the analog output voltage ranges obtained from $-V_{ref}$ to $\frac{127}{128}V_{ref}$. What is used in this chip in switching the start of the system transducer diodes is its unipolar type, which is biased with a reference voltage of -2.5 volts. Also, if this chip is used in voltage mode, it means that the analog voltage is applied to its feedback base and the output of the chip is reference base. At the chip output, the product of the analog voltage and the amount of digital information applied to the converter (in terms of ten) obtained. This technique used as a digital variable amplifier or D / A multiplier. Its gain controlled based on the amount of digital input of the chip. The usage of this mode shown in the main circuit for the U4 chip.

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Familiarity with the specifications of the device transducer

The transducer used in Nelker is made of two red and infrared LEDs as sources of radiant light to the finger and a bandwidth detector that detects red and infrared light. The 660nm red light emitting diode is made of Ga.As.p and the 940nm infrared light emitting diode is made of Ga, As. The maximum current that passed through the diodes to emit light is about 40 mA. The detector part of the transducer consists of a photodiode with a cross section of about 216 mm.

The detector is located under the finger, in front of red and infrared light sources. To get the most out of this detector output, simply apply the two ends of the output to the input of an instrumentation amplifier, which is a simple current-to-voltage converter with a large input resistance (photo-voltaic mode), and then filter the output of the amplifier. Of course, in this device, the detector output is first applied to a filter (RF to remove noise) and then the filter output is applied to the amplifier input. Detectors designed and manufactured in this type of transducers consist of the connection of p and n layers with an intrinsic semiconductor layer between them. With this structure, features such as high speed due to changes in light intensity and low noise reception created for the above detector. The main specifications of this detector given as numerical values in Table 2. When the transducer is connected to the system switching circuit, the red and infrared light emitting diodes are switched on and a finger is inserted into it, a signal appears at the transducer detector output. This signal is very weak, but at the output of the instrumentation amplifier has a favorable amplitude. This signal is converted by the blood flow and its attenuation effect on the intensity of light radiated to the finger, in the form of a pulse modulated with an amplitude proportional to the blood flow intensity.

Table 2. Main specifications of transducer detector

Parameter	Condition	Min	Normal	Max	Measure
Wavelength revealed	-	600	850	1.64	nm
Dark current	VR=20V	-	1	5	nA
NEP	VR=20V	-	3.6×10^{-14}	-	$W/\sqrt{HZ}$
Connection capacitance	VR=20V		3.5	-	PF
Response time	RL=50Ω VR=20V Λ=940nm	-	0.5	1	nS

Now if the amount of AC voltage changes to the amount of DC voltage generated at the output of the instrumentation amplifier, which is proportional to the intensity of light emitted to the detector, calculate in both red and infrared light. And find their ratio called R, the amount of SaO2 blood can be detected and displayed with the help of a curve and a calibration table. Also, if we calculate the AC signal amplification period in both red and infrared light (or count the signal frequency), we can get the number of heart beats per minute (HR). Because with each heartbeat according to part 10, an AC signal is generated by the blood flow pulse.

Numerical and message displays in the system

Seven-part displays were used to show the numerical amount of SaO2 in terms of percentage and heart rate of the patient per minute (HR). For the HR value, which can be displayed from 40 to 250, three screens have been used, and for the value 5.0, from the range of %99 to downwards, two screens have been used. All monitors are common cathode type and transistors which used base powered by 5 volts to pass the necessary current and turn them on for each one. Also, the anode of each diode in each display is connected to a current source, which has a current about 400 mA. There are seven current sources in the form of an integrated circuit in a chip numbered UDN2983, which biased by the supply voltage and volts. It should be noted that this chip is used for all monitors because the seven-part monitors turn on as a multiplex of time. A twenty-character LCD is used to display a variety of messages and the maximum and minimum acceptable SaO2 and HR values for the system and alarms. DB0DB7 digital information line is a control signal line (E) to activate, LCD a signal to write to or read from the LCD RAM, (R / W), a signal to control its brightness, and a signal to select the command register (IR) with its information register (DR). Fig. 14 shows the sequence of excitation of LCD control signals during writing in it.

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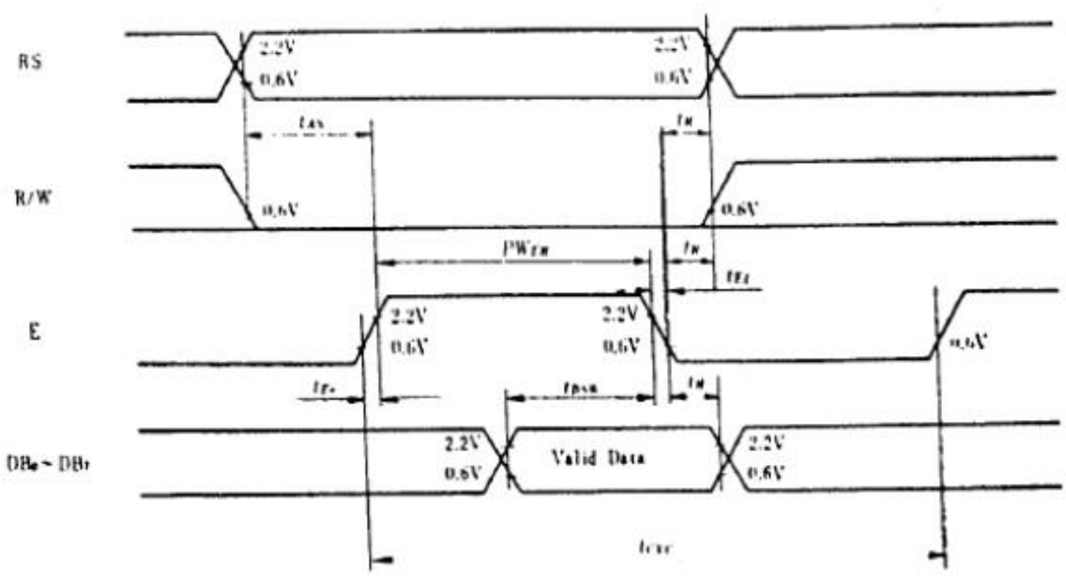

Fig. 14: Diagram of control signals in LCD during writing

Pulse oximetry system microcontroller

The heart of the pulse oximetry device consists of a microcontroller. This microcontroller is numbered C1078 from NEC company and includes the following features and capabilities.

1- ALU Sixteen bits
2- I/O Forty lines
3- Two 8-bit timers
4- A sixteen-bit all-purpose timer
5- Capable of direct addressing up to 60 KB
6- Eight channels of eight-bit AD converter
7- Ability to send and receive synchronous and asynchronous with peripheral devices as Full Duplex156
8- The command number includes multiplication and division of sixteen bits
9- Internal clock pulse generator (MHz 12)
10- Ability to receive
11- Interrupt source

Fig. 15 shows the internal structure of the microcontroller chip. As shown in Fig. (15), this chip consists of 5 eight bits ports, A, B, C, D and F, except for port D, each bit of the other ports can be programmed independently, as input or output. Port D is controlled as an input bite with an output bite. On the other hand, under software control, each bit port C can be used independently to connect other peripheral devices such as printers and monitors, etc. as synchronous or asynchronous.

A. 78C10 chip AD converter

One of the major advantages of the 78C10 chip is the presence of eight, eight-bit A / D converter channels within it. As shown in the figure below, eight analog signals can be applied to the chip via ANO to AN7. Each of these signals is selected at any time by an internal multiplexer and applied to the A / D converter and converted to 8-bit.

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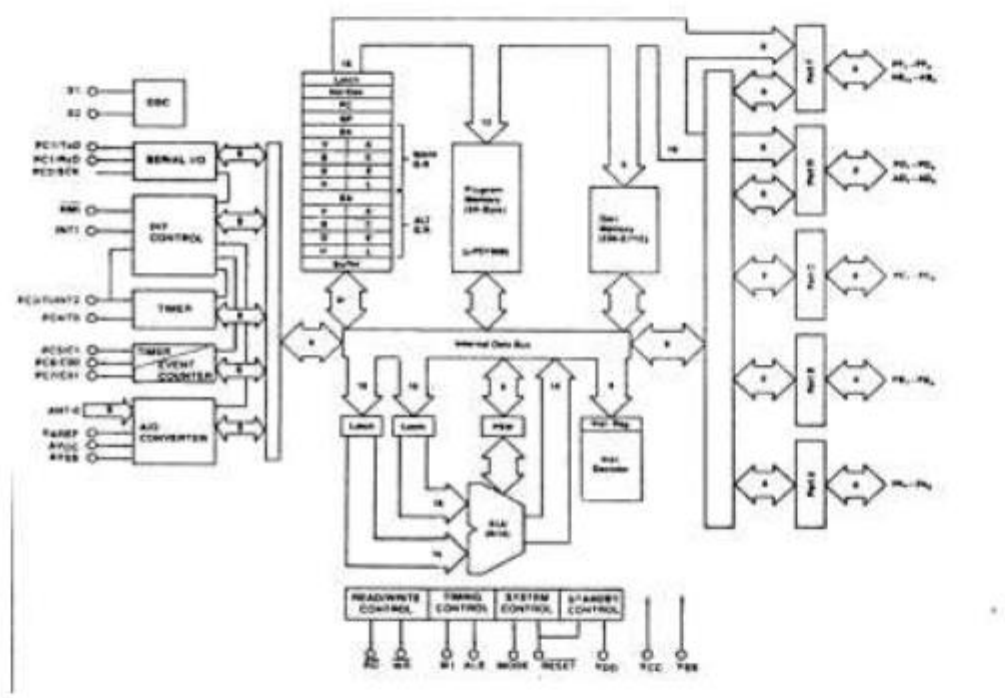

Fig. 15: Structure of 78C10 microcontroller

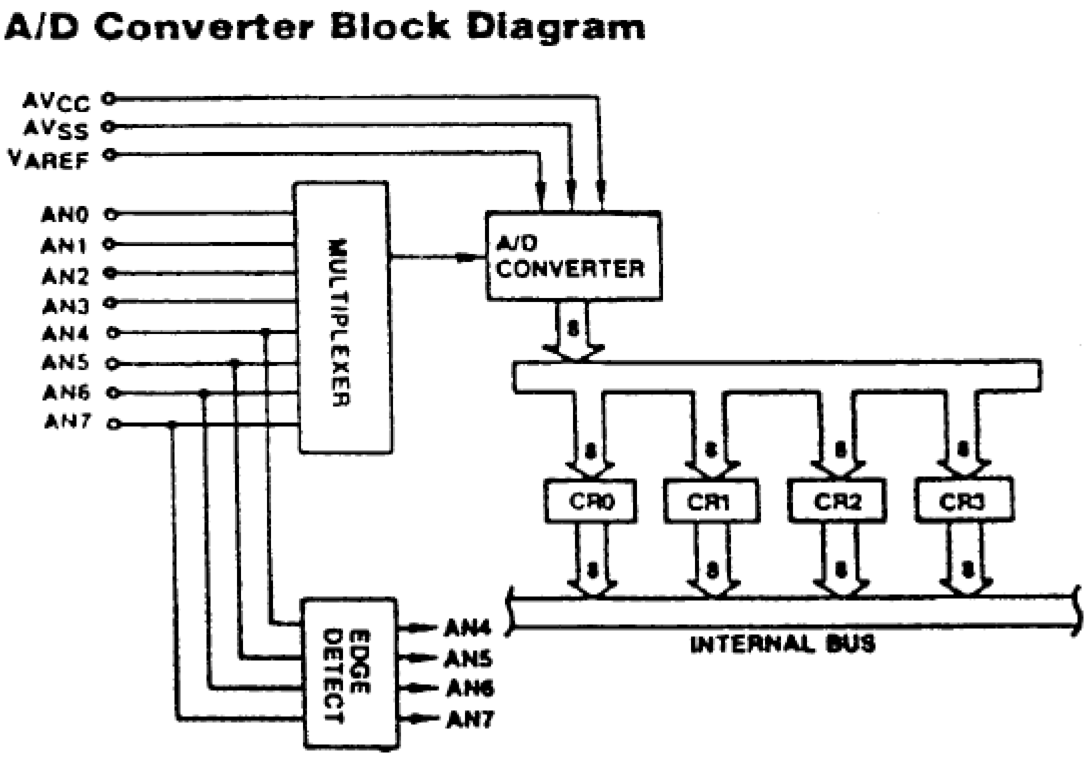

Fig. 15: Structure of 78C10 microcontroller

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In 78C10 chip, the characteristics of the A / D converter of the chip, which performs the conversion operation by the technique of consecutive approximations, are as follows:

1- Automatic sweeping mode
2- Channel selection mode
3- 1.5 LSB accuracy
4- Voltage conversion range from 0 to 5 volts
5- 50 µs Conversion time
6- Ability to interrupt

If the automatic vacuum mode is selected, first 4 channels with 4 channels are selected according to the type of programming and the result of converting the analog signal digitally is stored in CRO to CR3 registers and then the other 4 channels are swept. If the channel selection mode selected, the converted value of each input channel is stored in CRO to CR3, respectively. In the pulse oximetry system, an automatic sweeping mode was used to use this chip, which reference voltage is 5 volts.

B. Types of interrupts for 78C10

For this microcontroller, it is possible to receive interrupts from 11 sources. Of these 11 interrupts, three are external and eight are internal. These 11 interrupt sources are classified into six priorities. What is used of these 11 interrupt sources in this microcontroller in the pulse oximetry system is the interrupt resulting from AD.

C. Memory chips of pulse oximetry system

In addition to this microcontroller, a number of memory (27C256) EPROM and a memory (RAM) (61256) each in the size of 32 kbyte is used to store the system program as well as calibration values between R and 50 and record numerical information related to alarms and messages. Memories can be used with the help of two RD and WR signals and address lines 40 to A15, which are obtained by two ports D and F. A chip number consisting of eight flip-flops D can be used to store information because eight-bit information is exchanged between memory and the microcontroller via port D, the same port is used for the bottom eight lines of A0-A7 address. The ALE output base of the microcontroller does activation of the LE base of this chip. The following figure shows the order of the control signals and the addressing of the memory during reading it.

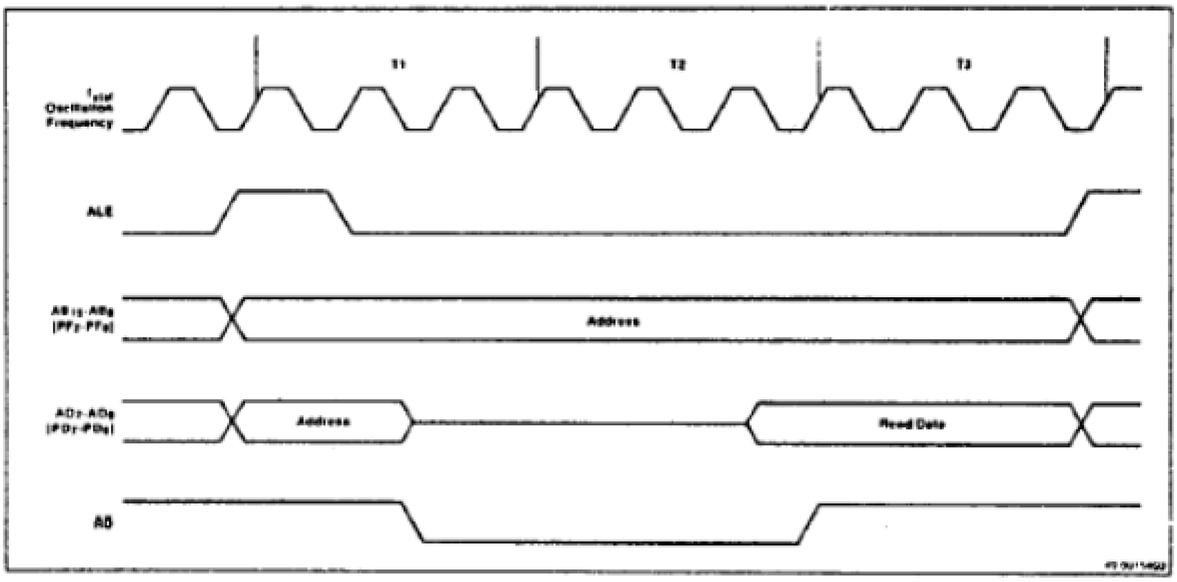

Fig..17: Memory Operation Cycle

Discussion and conclusion

The designed system, which is drawn in the previous section of its electronic maps, has the following specifications.

A. Technical specifications of the system

Determine the percentage of oxygen saturation from the range of 80 to ٪100 with an error of ٪1 on seven-part displays; 2- Specify the (HR) heart rate from 40 to 250 on seven-part monitors. 3- Specify the alarm, due to the low and high limit values for Sa02 and HR values on the screen (When the system is turned on, the upper limit of SaO2 is 99% and the lower limit is ٪90, and the upper limit of HR is 150 and the lower limit is 40 appears on the LCD screen.) HR High Limit Alarm: When the HR exceeds the specified maximum alarm value. HR Lower Limit Alarm: When the HR is less than the minimum value specified for the alarm. O2 High Limit Alarm: When S0 exceeds the maximum value specified for the alarm at the time of setting 0.5. Lower Limit Alarm: When 0.5 falls below the

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minimum value specified for the alarm at the time of setting 50. 4- Ability to operate the device by electricity or battery.5- The "Signal- Signal-probe Error" message appears when the finger is not inside the transducer.6- "Alarm Disabled" appears when the alarm switch for HR and SaO2 is activated. By pressing this key, the alarm detection can removed or created in the system. 7- The "Signal-OK" message appears when the system is in normal operation.8- "Searching" message appears when the system is in the red amplitude and infrared excitation signal setting mode.

B. Results of device testing

By turning on the system and placing your finger inside the transducer of the device, after a period of about 15 seconds, the amount of SaO2 and about 20 seconds, the amount of HR will appear on the seven-part monitors. The results of testing the device on a number of patients and comparing them with the values shown by Hewlett-Packard are shown in the table below.

Table 3. Comparison of system test results with HP device

Use of made pulse oximeter device		Use HP cardiac monitoring with pulse oximetry modulus	
SaO2%	HR	SaO2%	HR
95	85	95	80
97	78	96	72
93	95	95	88
86	103	90	93
83	95	85	110
99	78	98	78

Also, the transducer used in Hewlett-Packard's pulse oximetry system consists of a red diode with a completely plastic enclosure around the light sources and detector and By placing a finger inside it, no light from the environment reaches the transducer detector.

C. System bugs

HR values that are calculated and shown by the system have changes that can considered as the following reasons for the existence of these changes.

1- No silk layer on the printed circuit fiber

2- Connecting some points on the printed circuit fiber with wire

3- Unfavorable shield around the board in the indicator area, an error about 1% to 2% was found, which is acceptable

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