DIGITAL HEART RATE MONITOR
and
CLINICAL THERMOMETER

by

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Submitted to the Faculty of Graduate
School of Engineering in Partial Fulfillment
of the Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRICAL ENGINEERING

Boğaziçi University
1979

ACKNOWLEDGEMENTS

The following is not the work of a single person, but it has been realized with the help of many individuals.

First of all, I would like to thank Dr. Adnan Kahveci, my thesis supervisor, for his guidance and useful suggestions throughout the study. I also would like to thank Prof. Dr. Necmi Tanyolaç for his courses in which I gained the necessary background knowledge for this thesis.

I am very thankful to Prof. Dr. Yilmaz Tokad for permitting me to carry out this study at the Electronics Unit of TUBITAK.

I want to thank Mr. Ali Akurgal for his suggestions and great help in the construction of the instrument.

Also, I am very thankful to Mr. Cevat Gül for his practical suggestions.

Finally, my thanks go to Gülsen Karşit for the typing of this thesis.

ÖNSÖZ

Bu tez çalışmasında bir nabız sayıcı ve termometre tasarlanmış ve gerçekleştirilmiştir. Bu aygıt nabız ve sıcaklık için alt ve üst sınır uyarıcılarına sahiptir. Aygıt devamlı kalibrasyona gerek göstermemekte ve nabız için 20 ile 200 atım/dak. arasında % 5, sıcaklık içinde 30 ile 45 C arasında % 1 duyarlıkta çalışmaktadır. Tasarım alışılagelmiş TTL tümleşik devrelerle gerçekleştirilmiştir. Bu tasarım sırasında atılan en önemli adım böyle bir aygıtı yeterli duyarlıkta ve ekonomik bir şekilde gerçekleştirmektir.

Sonuç, ölçümleri gerekli duyarlıkta yapmak ve ekonomi açısından başarılı bir şekilde elde edilmiştir.

ABSTRACT

In this thesis, a heart rate monitor and digital thermometer has been designed and built. This instrument has low and high alarms for heart rate and temperature. The device does not need frequent calibration and has an operating range, for the heart rate monitor; from 20 to 200 beats/min with an accuracy of $\pm$ 5%, for digital thermometer; from 30 to 45^{o}C with an accuracy of $\pm$ 1%. The design is realized with usual TTL integrated circuit. The major goal was to produce a desk-top heart-rate-thermometer monitor which allows to calculate heart rate and temperature with enough accuracy, and to realize this in an economical way. The results obtained are quite satisfactory both in performance and economy.

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CHAPTER 1

INTRODUCTION

Biomedical Engineering seems to be a new branch of engineering. But, it begins in the Sixteenth century, the dawn of medicine, with Leonardo da Vinci (1452-1518). Da Vinci was a great artist and an engineer. He studied the motions of bones and muscle in extensive detail. Later, William Harvey (1578-1657), the great English physiologist, discovered that blood is pumped by the heart, and pointed out the differences in directions of flow in arteries and veins. After some other physiological developments, Galvani (1737-1798) and Volta (1745-1827) made studies of electrical phenomena in the body. They showed that external currents can effect muscles. After a few years Kölliken and Müller showed that during the contraction of the heart an electrical potential is produced. This potential was recorded in 1887 by Waller, who used a device called a capillary electrometer, introduced by Lippman in 1875. Now Biomedical Engineering helps medicine in a big area; stainless steel has been used extensively to repair joints and bones, nylon thread is a widely used surgical material. Artificial organs are used extensively; Heart-lung devices, heart valves, etc. Also, Biomedical Engineering can perform very many sensitive measurements.

These measurements are;

a. Bioelectric potential:

Bioelectric potential can be separated into three branches

i) ECG - Electrocardiography that is coming from the heart

ii) EEG - Electroencephology that is coming from the brain

iii) EMG - Electromyography that is coming from the muscles.

b. Skin resistance measurements

c. Cardiovascular measurements

d. Respiration

e. Temperature

f. Physical movements

g. Behavioral characteristics (sound, speech, taste, smell)

These measurements help the doctors in their diagnosis. Also these measurements help the development of medicine.

This thesis is based on two measurements; Heart Rate and Temperature. These parameters are very important for a person's state of health. These instruments are always used at bedside and central station monitoring assemblies for convenience in narration and analysis. In designing this instrument; reliability, economy and simplicity have been emphasized.

Before explaining the heart rate and clinical thermometer and going into details, it is worth to mention some properties of heart rate and temperature.

CHAPTER 2

HEART RATE

2.1. HEART

The heart is a living pump. It is a bundle of muscle cells, nerves, tubes and fibers. It is located in the upper chest cavity slightly to the left and below the center of the breast bone. It has four chambers, left atrium, right atrium, left ventricular, right ventricular. These chambers successively expand and contract so that the blood is alternally sucked in from the veins and lungs by the right and left atrium and squeezed out by the left and right ventricle through the arteries in order to supply the body tissues. These sucking and squeezing actions are initiated by the electrical action of the heart muscle itself. This electrical action of the heart is called Electrophysiology of the heart.

Electrophysiology of the Heart

The electrical action of the heart is the main peculiarity of the heart.

The electrocardiogram (ECG or EKG) is a graphic recording or display of this electrical action. The following factors are involved in the genesis of the ECG:

1. Initiation of impulse formation in the primary pacemaker (sinus mode).
2. Transmission of the impulse through the specialized conduction system of the heart.
3. Activation (depolarization) of the atrial and ventricular myocardium.
4. Recovery (repolarization) of all above areas.

In order to understand the ECG, it is necessary to have a basic knowledge of interacellular and surface potentials.

2.2. INTERACELLULAR POTENTIALS

If one electrode is placed on the surface of a resting muscle cell and a second indifferent electrode is placed in a remote location, no electrical potential will be recorded because of the high impedance of the cell membrane. However, if the cell membrane is penetrated by a capillary electrode, a negative potential of about 90 milivolts (mV) will be recorded. This is known as membrane resting potential (MRP). The major factor that determines MRP is the gradient of the potassium ions (K^+) across the cell membrane. The intracellular concentration of K^+ is approximately 150 MEq/liter, and extracellular concentration is approximately 5 MEq/liter. This K^+ gradient is 30/1. On the other hand, an opposite gradient exists for the sodium ions (Na^+). Under suitable conditions, distribution of ionic concentration will result in a potential difference between these different concentrations. This potential difference can be calculated by using the NERANST equation.

$$\text{Potential(mV)} = 61.6 \log \frac{\text{concent. oneside of memb.}}{\text{concent. of other side of m.}}$$

$$\text{Potential (mV)} = 61.6 \log \frac{1}{30}$$

$$= 61.6 \ (\log 1 - \log 30)$$

$$\text{Potential} = 61.6 \ (0\text{-}1\text{-}\log 3)$$

$$= 61.6 \ (1\text{-}1\text{-}0.478)$$

$$= - \ 61.1 \ (+ \ 1{,}478)$$

$$\sim - \ 90 \text{ mV}$$

For univalent ionic solutions, the formula is changed and potential is found by using the mobility of ions:

U - mobility of negative ions

V - mobility of positive ions

$$\text{Potential (mV)} = 61.6\ \frac{U - V}{U + V}$$

Na^+ gradient does not alter the MRP because the cell membrane is considerably less permeable to Na^+ than to K^+. It is estimated that the cell membrane in the resting state is 30 times more permeable to K^+ than to Na^+. Now, we have to look, what is the source of energy that allows for the high intracellular K^+ concentration and the negative MRP. As stated above, the cell membrane in the resting state is 30 times less permeable to Na^+ than to K^+, the former does pass across the cell membrane. Most electrophysiologists believe that the energy for maintenance of the MRP is derived from the Na^+. Theoretical considerations and some experimental evidence would seem to warrant the assumption that sodium enters the cell in an ionic form but leaves the cell in a nonionic form. This is referred to as the "active transport of sodium" or "sodium pump". Thus, it is thought that sodium ions enter the cell and produce the source of energy. The sodium ions then combine with some unknown interacellular substance, and this nonionic combination leaves the cell. At the onset of depolarization of a muscle cell, there is an abrupt change in the permeability of the cell membrane to sodium and potassium ions. Sodium ions enter the cell and result in a sharp rise of intracellular potential to + 20mV. This is associated with a migration of potassium ions outside the cell membrane. Following this rapid phase of depolarization, there is a relatively slow and gradual return to intracellular potential to the MRP. This is the phase of repolarization and is usually divided into 3 phases.

Phase 1 - An initial rapid period of repolarization.

Phase 2 - A plateau period of repolarization.

Phase 3 - The last period of repolarization; a slow, gradual return of the intracellular potential to the MRP.

Phase 4 - Membrane resting potential.

Figure 1 shows the diagram of the action potential of a ventricular muscle cell.

The duration of this curve from the onset of depolarization to the termination of repolarization is the duration of action potential. The monophasic action potential curve of the action of a ventricular muscle cell. Phase 4 (MRP) and depolarization are similar but Phase 2 is shorter in an atrial muscle cell. And the sino atrial (SA) node is markedly different from them. Figure 2 shows these differences.

The curve of sino-atrial node can also be divided 3 phase as the curve of atrial or ventricular cell. But it has a lower MRP (-60 to -70 mV) at the onset of diastole. Depolarization is slower and does not rich sufficient positive potential to be recorded on a surface electrocardiogram. The peak of the action potential is rounded and repolarization is a single slow curve in which phases 1,2,3 cannot be defined. The cells of sino-atrial node do not want any pulse to start depolarization. There is a gradual rise of the MRP during diastole. It is this prepotential that explains the automatic function of the sinus pacemaker. The sinus pacemaker works automaticly and it causes the atrial and ventricular depolarizations. The potential which is created by the cells spreads through the nodes to body. The source of these potentials is the SA node. From the SA node, the electrical potential goes to the AV node and it is reached right boundle of the heart and left bundle of the heart by the Punkinje fiber. At last, this electrical potential spreads through the heart to every point of the body. Because of these spreading, the conduction velocity is important. Velocity is most rapid in the Purkinje fibers and slowest in the mid-portion of the AV node.

The following figures are average values of animal species; SA node: 0.05 m/sec , atrial muscle = 0.8-1 m/sec; AV node = 0.05 m/sec, bundle of His 0.8=1m/sec, Purkinje fibers = 4 m/sec and ventricular muscle 0.9 - 1 m/sec.[2]

2.3. ELECTRODES, LEADS, AND THEIR PLACEMENT

We have discussed above how the heart beats are produced in the body. These bio-electric impulses travel due to each cell's depolarization. The action potential discussed previously occurs across every cell's membrane, and many of these acting together give rise to quite large electromagnetic fields and currents within the body. Fortunately, these electro physiological effects are detectable at the body's surface. Thus, if two electrodes are placed on the body's surface and the potential residing at each electrode site due to the heart signal is fed into a differential amplifier, then the heart's "electrical signal" can be recorded. Briefly, the twelve standard electrodes can be divided into three categories.

1. Bipolar limb leads (I,II,III), concerned with voltages between the limbs and the left and right sides of the body.
2. Unipolar limb leads (AVR, AVL, AVF), concerned with voltage differences between a particular limb and a central terminal potential point created by a resistance network placed between the other two limbs.
3. Unipolar chest leads (V leads), connected so as, to develop voltage differences between six chest electrode positions and a central terminal created by the midpoint of a Y-connected resistance network. Specifically, this network is formed by electrode leads from the right arm, left arm, and leg passing through three separate, equal resistances.

2.3.1. Bipolar Leads

Lead I delivers difference of potential between the left arm and the right arm. Lead II delivers difference of potential between the left leg and the right arm. Lead III delivers difference of potential between the left leg and the left arm. The relation between the 3 leads is expressed algebraically by Einthoven's equation:

Lead II = Lead I + Lead III

This is based on Kirchoff's law, which states that algebraic sum of all the potential differences in a closed circuit equals zero. If we sum three potential differences; (LA - RA) +(RA - LL) + (LL - LA) must equal zero. We could write this equation in this manner;

(Lead I) + (- Lead II) + (Lead III) = 0

The equation becomes,

I - II + III = 0

Then, I + III = II is obtained. Now, we can see the greatest lead is lead II. But because of connection simplicity, we have choosen Lead I in the heart rate monitor.

2.3.2. Unipolar Leads

i) Lead AVR delivers difference of potential between the right arm and the Wilson reference.

ii) Lead AVL delivers difference of potential between the left arm and the Wilson reference.

iii) Lead AVF delivers difference of potential between the left leg and the Wilson reference.

iv) Six unipolar chest leads deliver potentials between the chest electrode (this electrode places six difference points) and the true Wilson reference.

The Wilson reference: We have seen above that Lead I + Lead II + Lead III = 0. If we connect three limb (I,II,III) with a resistance network, it will result in a zero potential. This potential is the true Wilson reference. This reference is used to measure Unipolar chest leads. If we want to see unipolar limb leads, we disconnect a limb lead of the true Wilson reference that is measuring the limb. This degenerate Wilson reference is called the Wilson reference (Figure 6). Diagnostically, this means that the specific shape, amplitude, or duration of the various QRS and T waveforms tells a number of basic things about details or even about the overall mechanism. But our device tells us only the duration of the QRS. We have discussed normal and abnormal cardiac rhythm and its clinical significance in Chapter 8.

CHAPTER 3

TEMPERATURE

The production of heat, its internal transport and its dissipation from the human body are topics of great importance we would like to discuss the magnitude and source of heat production in the body, the ways in which heat is transported internally from one region of the body to another and heat losses.

3.1. HEAT PRODUCTION

The basal metabolic rate of an average person is about 72 kcal/hr. Basal metabolic rates are determined with "human calorimeters". The basal heat is produced in the body. The organs that are most active mechanically and chemically produce the most heat (liver, heart, brain). These active organs generally run 1^{o} or 2^{o} F higher in temperature than the surrounding tissues. In addition, the body "core" is warmer than the body's extermities and surfaces. Figure 7 shows isotherms in the body. Normal muscular activity can raise heat production to 125% or so of the basal metabolic rate, but at maximum activity this figure may be as high as 1500 ~ 2000% of BMR.[3]

The heat produced in the body is derived from breakdown, synthesis and utilization of food. Figure 8 shows how heat and external work are generated in the body.

Starting with 100 units of food energy, we see that 5% is ultimately lost in the form of entropy change. The rest of the food remains as potentially available free energy. The body utilizes all food as the formation of a compound called adenosine triphosphate (ATP). ATP is used to power all necessary functions, such as keeping the body repaired, synthesizing chemicals, fueling the heart and lung muscles, driving nerve impulses, etc. And also ATP is converted into external work. All processes except for external work entail a degredation of chemical energy into heat. Hence, if no external work is being performed, all food energy ultimately is converted into about 5% entropy and 95% heat.

Loss of Heat to the Environment

We have said all food energy is approximately converted into heat. It would be interesting to discuss, if there is no heat loss in the body. Let us assume a body weight of 68 kg, a heat capacity of 0.86 kcal/kg, - ^{o}C and basal heat production rate of 72 kcal/hr. Using

$$\frac{dT}{dt} = \frac{Q}{m.Cp}$$

we find that,

$$\frac{dT}{dt} = \frac{Q}{m.Cp} = \frac{72}{68 \times 0.86} = 1.2\ ^{o}C/hr$$

This result shows us, if there is no heat loss, the body temperature would rise 1.2^{o}C per hour. This result also indicates loss of heat to the environment is very important in human life.

3.2. LOSS OF HEAT TO THE ENVIRONMENT

Heat loss can be separated as follows:

a. Radiative heat losses from the body,

b. Convective heat losses from the body,

c. Evaporative heat losses from the body

i) Heat loss by diffusion of water through the skin,

ii) Heat loss by sweat secretion,

iii) Heat loss by evaporation of water into inspired air.

Now, we will briefly discuss this subject and the relationships between them.

3.2.1. Radiative Heat Losses from the Body

All objects continually radiate energy in accordance with the Stefan-Boltzman law, proportionately with surface area, emissivity, and fourth power of absolute temperature. If the surroundings that covers the body are hotter than the body surface temperature, a net heat gain via radiation occurs. When the surroundings are cooler, net heat loss occurs.

The loss of heat (or gain) from the body has been characterized by the equation;

$$Q_r = K'_r A_r e_s (T_s^4 - T_r^4)$$

T_s is the surface temperature of the body and T_r is the temperature of solid surroundings $(T_s^4 - T_r^4)$ can be expanded into two factors.

$$T_s^4 - T_r^4 = (T_s^3 + T_s^2 T_r + T T_r^2 + T_r^3)(T_s - T_r)$$

If temperature is a normal range of conditions, we take this factor into K_r' and the formula can be written as follows:

$$Q_r = K_r A_r e_s (T_s - T_r)$$

A_r is the effective area of the body, for a nude body, A_r is 80% of the total surface area, e_s is the emissivity of the body for incident infrared radiation, the absorbtivity of the human body is very high, about 0.97 and it is indepent of color. For visible light, the skin has an absorbtivity of about 0.65-0.82, depending on whether it is white or dark respectively. We could estimate an average value for K_r, Ruck and Patton (1965) cite

K_r is 7 kcal/hr-m²-C°.

3.2.2. Convective Heat Losses from the Body

Convective heat losses from the body is characterized by this formula,

$$Q = K_c A_c (T_s - T_a)$$

T_s and T_a are surroundings and ambiend temperatures. A_c is the effective area for convective transport. A_c is generally about 80% of the total surface area, for a nude body. K_c is a convective heat transfer coefficient. Convective heat losses can be separated as "free convection" and "forced convection" heat transfer on the activity of surrounding environment. If there is no air velocity to the person, pure free convection occurs and, if there is a definite velocity of air to the person, the forced convection occurs. K_c is defined as either free or forced convection in two ways. If there is free convection we would take that K_c is equal to 2.3 kcal/m²-hr-C°. If there is "forced convection" K_c can be defined approximately by this formula:

$$K_c = 5.6\ v^{0,67}$$

Forced convection is more important than free convection. We would see this in a simple example. In our example $T_s = 33^oC$, $T_a = 29^oC$ and $A_c = 1.8\ m^2$.

We take two cases:

First, there is no air movement and free convection occurs. Heat loss is;

$$Q_c = (2.3)(0.8)(1.8)(33-29) = \underline{\underline{13.24}}\ \text{kcal/hr}$$

Second, there is an air movement and air velocity is 1m/sec (3.6 km/hour). Forced convection occurs. Heat loss is;

$$Q_c = 5.6 \cdot 1^{0,67} (0.8)(1.8)(33-29)$$

$$= 32.25 \text{ kcal/hour}$$

If we think that BMR is 72 kcal/hr we can understand that heat convection losses are very important.

3.2.3. Evaporative Heat Losses from the Body

We have said evaporative heat losses occur by several nechamisms. These are as follows:

i) Heat loss by diffusion of water through skin:

Water diffusion through human skin is about 350 ml/day in an average person. The diffusional heat loss Q_d is proportional to the difference between the vapor pressure of water at skin temperature (P_s) and the partial pressure of water vapor in ambient air (P_Q). Q_d is also proportional with the surface area of the body (A_N). The formula can be given as follows:

$$Q_d = 0.35\, A_N\, (P_s - P_A)$$

P_s can be represented well by the formula;

$$P_s = 1.92\ T_s - 25.3 \text{ mm Hg}$$

Supposing that $T_s = 33^oC$ and $P_a = 25$ mmHg, then;

$$P_s = 1.92(33) - 25.3 = 38.1 \text{ mmHg}$$

$$Q_d = 0.35\ A_N(P_s - P_A)$$

$$= (0.35)(1.8)(38.1) - 25) \simeq 8 \text{ kcal/hour}$$

This value is 11% of the BMR. Also this represents the evaporative heat loss associated with 340 mL/day, since the latent heat of vaporization of water is about

$$570 \text{ kcal/kg at } 33^oC$$

$$Q_d \simeq 8.24 = 192 \text{ kcal/day}$$

$$\frac{192}{570} \simeq 0.340 \rightarrow 340 \text{ mL/day}$$

ii) Heat Loss by Sweat Secreation

When activity levels rise above the basal state, additional heat is produced in the body. And the body needs to cast off more heat then the body arises.

one of the automatic mechanisms for increasing heat loss is the sweating response. One can see that the maximum amounts are quite large - up to 5 or more liters each day. The evaporation process can be formulated in two methods.

Firstly, in dry air; the evaporative heat loss in kilocalories per hour is,

$$Q = 570\ m^{o}_{w}$$

m^{o}_{w} is the rate of water excretion by the sweat glands in kilograms per hour.

Secondly, in stagnant and moist air,

$$Q_e = K_e\ A_w\ (P_s - P_d)$$

A_w is wetted surface area, P_s and P_d are water partial pressures corresponding to the surface and ambient conditions, and K_e is an evaporation transfer coefficient. K_e have been experimentally determined by Clifford and it can be found by these formulas:

$$V > 0.58\ \text{m/sec} \rightarrow K_e = 12.7\ v^{0.634}$$

$$V < 0.51\ \text{m/sec} \rightarrow K_e = 9.66\ v^{0.25}$$

iii) Heat Loss Associated with Respiration

When air inspired, heat and water vapor are transferred to it by convection and evaporation in the deepest parts of the lungs. As the air moves outward through the respiratory tract some heat is transferred outward. Heat loss can be described by the equation;

$$Q_{eL} = m_a^o \, (Y_o - Y_1) \, \lambda$$

where m_a^o is the kilograms of air breathed in and out per hour (dry basis) Y_o and Y_1 are expired and inspired air water contents (in kilograms of water per kilogram of dry water), and λ is the latent heat of vaporization of water at the expired air temperature (kilocalories per kilogram).

The pulmonary ventilation rate m_a^o is primarily a function of metabolic rate and follows pretty well the relationship

$$m_a^o = 0.006 \, M$$

where M is the metabolic rate in kilocalories per hour.

We have seen above the production of heat and its dissipation from the human body. We have started with 100 units of food energy and have seen that all processes, except for external work and enthropy are converted into heat. And this heat dissipates from the human body. We can explain these processes with the following formulates:

$$\text{Food} = \text{Entropy} + \text{Heat} + \text{External work}$$

If there is no external work

$$\text{Food} = \text{Etropy} + \text{Heat}$$

$$\text{Entropy} = 5\%\ \text{food}$$

$$\text{Heat} = 95\%\ \text{food}$$

$$\text{Heat} = Q_r + Q_c + Q_d + Q_e + Q_{eL}$$

$$= K_r A_r e_s (T_s - T_r) + K_c A_c (T_s - T_r)$$

$$+ 0.35\ A_N (P_s - P_a) + K_e A_w (P_s - P_a)$$

$$+ m_a^o\ (Y_o - Y_1)\ \lambda$$

CHAPTER 4

DESIGN OF HEART RATE MONITOR

4.1. DESIGN CONSIDERATIONS

A digital beat-to-beat cardiotachometer which calculates heart rate digitally in a simple manner has been constructed. The device needs no calibration and has an measuring range from 20 to 200 beats/min. We would like to feel that a need could be fulfilled with this instrument which had the following specifications:

i) Digital display of heart rate

ii) Display updated every beat to the value obtained over the preceding period.

iii) Minimum and maximum alarms in a digital manner

iv) Easily applied transducers

v) No controls except ON/OFF switch

vi) Range of 20 to 200 beats/min

vii) Accuracy of 5%

This part of the thesis describes the principles and circuitry of such an instrument.

4.2. THE PRINCIPLES OF CARDIOTACHOMETER

ECG signal is a low frequency signal. Measuring the frequency of this low frequency signal directly is a slow precess, since enough signal cycles must be counted to give the needed resolution. The normal approach to the problem of calculating heart rate beat-to-beat in a digital manner would be to measure the time between heart beats and then divide this number into 1 to obtain the heart rate in beats per minute. This method is very accurate but involves some complicated digital electronics. We have devised a method of calculating rate which gives needed accuracy but which is much simpler to implement. And with this method an alarm circuit can be designed easily. We want to discuss the principles of some other important heart rate measurement techniques before the explanation.

4.3. ALTERNATIVE HEART RATE MEASUREMENT TECHNIQUES

A variety of circuits have been described in the literature which count and display heart rate. And we know that digital display is used in a wide area, but first of all we want to describe a simple technique for instantaneously measuring frequency with an output that is linear to within two beats.

4.3.1. The First Technique[11]

In this method, there are two RC networks which are alternately charged and discharged. We know that a capacitor is charged with an exponential function

$$V_m = V_B \ (1 - e^{-T/k})$$

T is the interval between pulses and k is the RC time constant. This relationship is shown in Figure 9 for one particular time constant k = 0.3.

This figure shows us how the voltage changes with time interval. But we are interested in the relationship between voltage and frequency. This relationship is shown in Figure 10 for the same time constant k=0.3.

We could see that the relationship between frequency and voltage are linear between 40 and 200 beats/min. This linear charging curve can be best approximated by a hyperbola in the first curve. Now, we have understood that, a capacitor can convert frequency into voltage in a narrow band. If we use two RC networks which are alternately charged and discharged, we could measure frequency with these capacitors alternately.

Now, we see the circuit in Figure 11. The ECG signal is amplified with a preamplifier and is converted to a single pulse. This pulse drives the bistable. Each pulse changes the output Q and $\overline{Q}$. Then, C_1, and C_2 are alternately charged and discharged. V_1 and V_2 which are the voltages of C_1 and C_2 give us the frequency value as the volt. Isolating amplifier prevents the discharge of the capacitor, because it needs practically no current. With this method we could measure heart rate easily, but measuring of the frequency linearly has some hardware complications, because of this region, we have chosen a digital display for read-out.

4.3.2. The Second Technique[12]

Researchers at the Institute of Environmental Stress at the University of California at Santa Barbara expressed a need for an accurate heart rate monitor which could monitor heart rate either beat-to-beat or averaged over various numbers of beats. This device consists of a digital "clock" which, instead of reading t in minutes, reads 1/t. Thus, if one heart beat is used to start clock and the next beat is used to display the clock reading. This clock can be introduced " $\frac{1}{t}$ clock". This " $\frac{1}{t}$ clock" works in the following manner: a 3-decade down counter which is initially set to 999 at $t = 0$ is counted down. If the counter frequency changes with time as follows,

$$\frac{dR}{dt} = - R^2$$

where R is the number in the down counter shows us the rate. We could see this result, integrating the first equation from 0 to t.

Then we obtain;

$$R = \frac{1}{t + \frac{1}{R_o}}$$

where R_o is the initial number in the counter. But, we would like to obtain the true value R_T.

$$R_T = \frac{1}{t}$$

The earliest time this can be satisfied is the inverse of the largest number R_o that the counter can contain. Thus, we wish to reset the count to R_o at;

$$t_{reset} = \frac{1}{R_o}$$

At the reset time

$$R_{reset} = \frac{1}{\frac{1}{R_o} + \frac{1}{R_o}} = \frac{1}{2} R_o$$

In this case, the counter resets to 999 when it first reaches 500 after this time, the number in the down counter is always $\frac{1}{t}$ until the clock is stopped. Now, we can examine the block diagram of $\frac{1}{t}$ clock in Figure 12, and then, we could see how to obtain

$$\frac{dR}{dt} = - R^2$$

in " $\frac{1}{t}$ clock". Now we can see that f_1 is;

$$f_1 = \frac{f_o R}{1000}$$

Then f_2 can be found that,

$$f_2 = \frac{f_1 R}{1000} = \frac{f_o R^2}{10^6}$$

for

$$f_o = 16.66 \text{ KHz} \qquad f_2 = \frac{16.666}{10^6} R^2 = \frac{1}{60} R^2$$

f_2 is also equal $\frac{dR}{dt}$ per minute. Complete circuit diagram is in Figure 12.b.

In this circuit, CD4527 can be used as a rate multiplier, and we could choose CD4029 as a down counter. But these integrated circuits are not found easily. If the circuit is designed with these components, it is not low-cost and its alarm circuit needs complicated circuitry.

4.3.3. The Third Technique[13]

As we have said before, there are several methods for measuring heart rate. The second method is more simple than the method which we have discussed above. In this method, four counters are required. The block diagram of circuit is shown in Figure 13. Now, we will explain these counters.

Counter A - measures the period of the unknown signal by counting the number of clock pulses. The number N which is length of the measuring period performs B.

Counter B - which is a programable divide-by-N unit.

Counter C - creates a burst with a fixed number of pulses K.

Finally, K/N pulses, which comes from counter B are accumulated by Counter D to display its frequency.

Now, we would like to discuss how to design a heart rate monitor with this method. First of all we have to find F which is period-clock frequency. Heart rate is changed from 20 to 200. If we want to measure with 2% accuracy at 200 beats per minute, the signal period is 0.3 seconds. To measure the rate to 2%, 50 clock pulses must be counted in this time, so the clock frequency must be $\frac{50}{0.3}$ = 166.7 Hz. At 20 bpm, the signal period is 3 seconds. Counting clock pulses for this time results in 3 x 166.7 = 500 counts, so counters A and B are each 9 bits. The pulse burst must give a quotient of 9 with 500 counts, so it must be 4500 counts long; therefore, K is 4300, and counter C thus requires 13 bits. Counter D, the display register, must count up to the maximum of 200.

Three BCD decades will suffice in Figure 14, complete circuit diagram is shown.

4.3.4. The Fourth Technique

We would like to give another circuit design with the same principles. In this design, two D type flip-flops are used to produce a pulse of 15 miliseconds wide synchronized with clock and input. We have 135kHz clock and 135 kHz gives us 2048 pulses in 15 msec. 2048 pulses are used to give K pulses. If we use 33 Hz as a period clock, our K/N pulses gives us heart rate in 20 to 200 pulses. Figure 14 shows the block diagram of the instrument.

4.3.5. The Fifth Technique[14]

We would like to give a heart rate meter which measures heart rate more accurate. One main purpose of this device is to provide a more accurate means of determining when a pacemake should be replaced. This circuit performs the necessary arithmetic and control functions for digital division and control the counter display logic.

The division performed is 600.000/K, where K is in miliseconds. The division algorithm is implemented by a counting technique that utilizes the interval signal K. The interval signal is gated with a 1KHz clock to form a signal KF1. This is sent into a 12 bit binary counter (counter A) to obtain a number M, M is transferred to a latch and compared with the contents of a second counter, B. Each time the latch output equals the contents of the counter B, the digital comparator outputs a pulse to the counter display unit.

The block diagram is given in Figure 15.

Now, we would like to explain a new heart rate meter design.

4.3.6. The Sixth Technique[15]

The Russian pulse-frequency measurers developed an electronic digital pulse rate counter, the RVM-01. It enables both instantaneous and mean heart and pulse rates to be measured. And an alarm signal is given when the frequency moves outside the set limits. This device consists of four important parts; "amplifer-selector", "period code", converter", "digital counter" and "automation unit".

The first part is "amplifer-selector". For the sake of simplicity, no amplifier is provided for the biopotentials, but ECG signals is taken from an electrocardioscope or electrocardiograph. To eliminate low frequency components, the ECG signal passes through a high pass frequency filter (HFF). From the output of the amplifier (A) the signal enters the input of a low-pass frequency filter which mainly determines the accuracy of the pulse interval. The pulse which comes (LFF) passes through the threshold device (ThD) and blocking device (BD). These devices select the ECG signals and reject noise. Figure 16 shows us the

Amplifier-Selector.

The output of the amplifier selector, square pulses which are cynchronized with QRS spike are obtained. These pulses enter the period-code converter. The period-code converter operates as a reverse pulse-time converter. The principle of period-code converter is based on the condenser charging. Input pulse of the period code converter comes to the univibrator UV1. The univibrator returns the decade pulse counter (C1, C2 and C3) to zero in the digital counter section. The trailing edge of this pulse puts the trigger (tr) into position "1". When this occurs, the controlled saw tooth generator (CSTG) is charged with I_c.

$$U_{CSTG} = \frac{I_c \cdot t}{C} \qquad (1)$$

where t is the time elapsed. C is the capacity of the capacitor of the CSTG.

I_c is directly proportional to the controlling potential

$$I_c = K_1 \quad U_{STG}$$

K_1 is a constant.

The potential U_{CSTG} passes to the input of the comparator (COMP). When U_{CSTG} is attained U_{ref}, a "stop" pulse is sent to Tr and the system returns to the starting condition. Now, we can see how we obtained U_{STG}. U_{STG} is proportional with T_x which is the time interval measured.

$$U_{STG} = K_2 \, T_x$$

The time τ is found from (1). In this equation, when U_{CSTG} equals U_{ref} t is τ.

$$\tau = \frac{U_{ref} \cdot C}{I_c}$$

$$\tau = \frac{U_{ref} \cdot C}{K_1 \, U_{STG}} = \frac{U_{ref} \cdot C}{K_1 \, K_2 \, T_x} = K \frac{1}{T_x}$$

In a time τ, N pulses of frequency f_{ref} from a reference LC generator enter the input of the digital counter:

$$N = \tau \, f_{ref} = K_c \, f_{ref} \, \frac{1}{T_x}$$

Figures 16 and 17 show us the period-code converter and its operation.

4.4. IMPLEMENTED DESIGN

We have described different types of medical and physiological investigations in heart rate measurement. But these often have some expensive components or do not have the following specifications. It was felt that a need could be fulfilled with an instrument which had the following specifications and works with basic electronic components.

i) Circuit has to be designed with low cost components which could be found easily.

ii) The same circuit has to be used as a temperature measuring instrument in addition with minimum amounts of components.

iii) Easily applied transducers.

iv) Range of 20 to 200 beats/min.

v) No controls except ON/OFF switch.

vi) Digital display of heart rate and temperature monitoring.

This section of the thesis describes the principles and circuitry of this instrument.

We have devised a method of calculating rate which is equally accurate but which is much simpler to implement. We could see this instrument in four subsections; QRS to squared pulses converter, time to frequency converter, counter and isolated power supply.

First of all, we would like to explain how to measure heart rate with this instrument.

4.4.1. The Basic Principle of Heart Rate Monitor[16]

The block diagram of this instrument is shown in Figure 18. The QRS spikes are converted to square pulses by a analoque circuit. Then we want to measure the frequency of these pulses which is the inverse of the interval between these pulses. This measurement may be summarized by the following equations.

If we charge a capacitor with fixed current, the capacitor voltage is:

$$V = K \cdot T$$

When we charge the capacitor C between two heart pulses, the capacitor voltage is;

$$V_1 = K_1 \, T_1$$

K_1 is a constant which depends on C

T_1 is the interval between two pulses

If we control the pulse length of a monostable with this voltage, pulse length is:

$$T_2 = \frac{K_2}{V}$$

K_2 is a constant depending on the monostable capacitor C_2.

T_1 was input period. T_1 can be written as $\frac{60}{f_1}$ where f_1 is the heart rate in beats per minute, therefore:

$$T_2 = \frac{K_2}{V} = \frac{K_2}{K_1 T_1} = \frac{K_2}{K_1 \frac{60}{f_1}} = \frac{K_2 f_1}{K_1 60}$$

If this pulse of length opens a gate and allows clock pulses through at a rate C hertz then clock pulses admitted to the counter

$$\text{Clock pulses} = C \cdot T_2$$
$$= C \frac{K_2 f_1}{K_1 60}$$

If $\frac{CK_2}{60K_1} = 1$ then pulses in counter f_1 and these can be decoded and display directly.

4.4.2. Circuit Description

-QRS to squared pulse converter.

First of all, in order to obtain clean, artifact free ECG signals, conventional electrodes are attached to the sternum of the patient. As we have seen, Lead I configuration is the most useable lead. For this connection, electrodes are attached between the left arm and right arm. The last electrode is connected to the left leg for grounding. After these connections, we obtain a QRS spike at the input of out differential amplifier. Now we have to amplify this signal and also we have to eliminate all interference and noise. The QRS spikes which come from the human body have some noise, this noise is of the same magnitude and the same shape in both leads. Because of this, when a differential amplifier subtracts these two signals which come from the right and left arm, the noise of the inputs cancel each other and the main signal QRS is obtained from the output of the differential amplifiers. The electrodes which come from right and left arm are connected to the noninverting inputs of two operational amplifiers A_1 and A_2. The important factor of the design of this amplifier is the effect of the electrode contact on the patients' skin.

This junction impedance value effects the faithful reproduction of the ECG amplitude as follows:

$$\text{ECG out of preamplifier} = \frac{\text{Input impedance of Preamplifier}}{\text{Input impedance of Preamplifier} + R_{\text{Electrode}_1} + R_{\text{Electrode}_2}} \times \text{ECG amplitude}$$

Consider the situation where the electrode is attached to the patient with an electrolyte cream to enhance the contact (to lower the junction impedance). The electrolyte impedance could easily be 50K-ohms. We choose (470K+470KΩ) input impedance. This means:

$$\text{ECG out of Preamplifier} = \frac{940\ \text{K}\,\Omega}{(940 + 100)\text{K}\Omega} \times \text{ECG amplitude}$$

This results in 90% of the actual patient ECG being reproduced by the preamplifier. In this way we obtain ECG signals to amplify the input of (A_3) differential amplifier.

Frequency Response:

The frequency response of the ECG amplifier is defined as the maximum frequency to which the instrument can respond and maintain the calibrated amplitude within 70.7% of the true signal. The American Heart Association specifies a minimum frequency response of 0.05 Hz to 100 Hz. The frequency response is important to insure that accurate amplitude measurements will be obtained. But out device is not an ECG amplifier, that means we do not want to see any shape changes of QRS, we only want to measure heart rate. Because of this reason, we could take a frequency band which shows only QRS spike. Our preamplifier has two stages, first stages have low and high peak points of 2 Hz and 18 Hz respectively, and differential stage 1Hz and 34 Hz.

At the output of differential stage A_3 we obtain a QRS spike which has a magnitude of 2 to 3 volts. This signal is then passed to the stage incorporating A_4, which is an absolute value amplifier. Thus at the output of this stage only positive going signals appear which are applied directly to the noninverting terminal of A_S. A_S is used as a comparator. The peak value of the signal is also transferred to C8 and the inverting terminal of the comparator. Assuming T_{r_3} is OFF capacitor is allowed to discharge in an exponential manner dictated by R_{21}. Diode D_4 is to replace the voltage dropped by D_3. Thus the last peak voltage of the signal (decayed somewhat) is stored on C8 and as the signal exceeds the stored value on the next QRS spike the comparator switches from V^- sat to V^+ sat and back. The diode D_5 is to prevent the comparator pulling the TTL monostable input to below 0 volts. The purpose of T_{r_3} requires a little explanation. The decay of the voltage on C8 has to be such that it does not allow the comparator to switch due to the T wave of the ECG or noise on the signal during the longest periodic time, which is 3 sec (20 beats/min). However, at switch ON, the transients in the amplifiers take the voltage on the capacitor to V_{sat} and, if the subject has a very low amplitude, the settling time of the instrument could be unduly long. The ramp, however, reaches the bottom of its sweep after 3 sec, and so, when this happens, T_{r_3} is ON and the 18 kΩ in the collector of T_{r_3} brings the voltage on C8 down much more rapidly. In normal steady state use, therefore, the fast decay circuit is inoperative.

Now we have obtained a square pulse which is in synchronism with the QRS spike the complete circuit diagram of this part is shown in Figure 19. Time to Frequency Converters.

As we have explained, the QRS to square pulse converter gives us a square pulse which is synchronized with the QRS spike. This pulse triggers the "dead time" monostable. The dead timemonostable provides a dead time of 300ms. This dead time prevents the counting signals which have repitiations larger than 200 Hz. On the rising edge of "dead time" monostable, however, triggers another monostable of about 140 nsec duration. Whilst the output from this monostable is in the high state it resets the decade counters, and when it falls the voltage controlled monostable and minimum and maximum alarm monostables are triggered. Voltage controlled monostables gives us a pulse whose length is inversely proportional to the voltage on pin 11, or is proportional with the capacitor C which is connected pin 10 and 11. When the voltage controlled monostable pulse falls, the ramp resetting monostable emits a 3 ms pulse.

Now, we will see how the voltage of V.C.M change with heart rate.

R_{25}, R_{26}, R_{27} and T_{r_4} make up a constant current source and this current source charges the capacitor C10 with constant current. If ramp resetting monostable is triggered, T_{r_6} and T_{r_5} are fired, However, T_{r_5} decharges the capacitor C10. And the voltage of point A rises to 10 volt. After this time, C10 charges linear fashion. As C10 charges in linear fashion, the voltage of point A drops from 10V to lower limits. This dropping continues between two pulses. The voltage of point A which depends on the charging of capactior C10. V_A can be written as follows:

$$V_A = 10 - K\,T \text{ (volt)}$$

$$= 10 - \frac{I}{C} \cdot T$$

V_A passes through T_{r_7} and T_{r_8} - T_{r_9} and R_{31} forms a constant current source. The purpose of A_6 is to measure voltage drop due to the base emitter junctions to T_{r_7} and T_{r_8} and reapply it to the top of R_{31} to correct for the error which would otherwise result. Now, we can look at the operation of this section.

The purpose of A_6 and the output of T_{r_8} which goes to voltage controlled monostable requires a little explanation. T_{r_7}, T_{r_8} and A_6 make up a converter which converts voltage to current. Input voltage of this system is V_A and output current I_{out} goes to the voltage controlled monostable.

We could see the relationship between V_A and I_{out} with the following equations:

$$V_A = \text{input voltage}$$

ΔV_1 = The base emitter junction voltage of T_{r_7}

ΔV_2 = The base emitter junction voltage of T_{r_8}

The simplified block diagram of it is given in Figure 20.

Using the principle of superposition output voltage V_o is:

$$V_o = V_A\ (-1) + \frac{V + \Delta V_1 + \Delta V_2 + 10}{2} \cdot 2$$

$$V_o = -V_A + V_A + \Delta V_1 + \Delta V_2 + 10$$

$$V_o = 10 + \Delta V_1 + \Delta V_2 \text{ (Volt)}$$

However, the output current of T_{r_8}, I_{out}, is found as follows:

$$I_{out} = \frac{V_o - V_B \text{(Volt)}}{10\ k\ \Omega}$$

$$= \frac{10 + \Delta V_1 + \Delta V_2 - (V_A + \Delta V_1 + \Delta V_2)}{10\ k\ \Omega}$$

$$I_{out} = \frac{10 - V_A \text{ (Volt)}}{10 (k\Omega)} = \text{(mA)}$$

Our monostable multivibrator is SN74121. This monostable works with timing resistance whose range is 2kΩ to 40 kΩ, throughout these ranges pulse width is defined by the relationship:

$$t_p(\text{out}) = C_T R_T \log_e 2 \simeq 0.7\, R_T C_T$$

We do not use R_T in VCM, we use constant current source formed by T_{r_8} and R_{31} instead of R_T. In the formula of $T_p(\text{out})$, R_T can be replaced by I_T as follows.

The formula of $t_p(\text{out})$ is used when external resistor and capacitor are connected as in Figure 21.

As we have seen, R_T produces a current which is $I_T = \frac{5V}{R_T}$. Now, we could say;

$$R_T \cong \frac{5V}{I_T}$$

Then,

$$t_{p_{out}} = 0.7\, \frac{5}{I_T} \cdot C_T$$

I_T is equal to the output current of T_{r_8} • I_{out}.

$$I_{out} = \frac{10 - V_A\ (\text{Volt})}{10\ k\ \Omega} = I_T$$

$$t_p(\text{out}) = 0.7 \cdot \frac{5}{\frac{10-V_A}{10\ k\Omega}} \cdot C_T$$

$$= \frac{35.10^3}{10-V_A} \cdot C_T$$

In our curcuit C_T was chosen as 0.005 pF.

$$t_p(out) = \frac{35.10^3 . 5 . 10^{-9}}{10 - V_A}$$

As we have seen

$$V_A = 10 - K\ T$$

$$t_{p_{(out)}} = \frac{35.5. .10^{-6}}{K\ T} ; \quad K = \frac{I}{C}$$

$$t_{p_{(out)}} = \frac{175.\ C10}{I_{st} \cdot T} \cdot 10^{-6} \text{ sec}$$

$$= \frac{175 , C10^{(F)}}{I_{st}\ (A)} \cdot \frac{1}{T_{(SN)}} \cdot \mu \text{ sec}$$

This pulse ($t_{p_{(out)}}$) choppes with 1 MHz clock and the output of them is sent to the counter.

$$\text{counting number(beats/min)} = t_{p_{(out)}}(\text{sec}) \cdot f_{clock}(\text{Hz})$$

or,

$$= t_{p_{(out)}}(\mu\text{sec})\ f_{clock}\ (\text{MHz})$$

We have chosen the clock frequency 1 MHz. Now, we can write;

$$\text{Heart rate} = t_{p_{(out)}} \quad (\mu sec)$$

$$t_{p_{(out)}} = \frac{175 \, . \, C_{10}(F)}{60 \, . \, I_{st}(a)} \cdot \frac{60}{T_{(sec)}} \quad \mu \text{ sec}$$

$$t_{p_{(out)}} = K \cdot \frac{60}{T_{(sec)}}$$

goes directly to the seven segment displays. And the counting number is visualized in displays. This device has three 7 segment displays. The complete circuit diagram of the counter is shown in Figure 22.

CHAPTER 5

DESIGN OF THERMOMETER

5.1. DESIGN CONSIDERATIONS

A digital clinical thermometer which measures body temperature digitally has been constructed. The device has an operating range between 30 to 45°C. In the design of this thermometer, economy was the most important factor. Because of this reason our design had to use as few as possible number of components. Now, we would like to discuss some thermometer scales.

5.2. THERMOMETER SCALES

There are four thermometer scales. The first, the centigrade scale, divides standard interval between freezing point of water and boiling point of it into 100 equal parts called centigrade degrees. Second, the Fahrenheit scale, divides the standard interval in

180 equal parts called the Fahrenheit degrees. Kelvin divides the standard interval in 100 equal parts called Kelvin degrees and Rankie divides the standard interval in 180 equal parts called Rankie. Freezing point of water is 0^oC, 273^oK, 32^oF and 492^oR.

These scales may be converted to centigrade as follows:

$$C = \frac{5}{9}\,(F - 32^o)$$

$$C = K - 273,\ 16^o$$

$$C = \frac{5}{9}\,(R - 491.69)$$

Body temperature is usually measured with the centigrade scale. Because of this reason we used the centigrade scale.

Temperature can be measured only by indirect methods. We generally transfer heat to an instrument designed to respond the energy so transferred.

Temperature can be measured with these instruments:

i) Mercury-in-glass thermometer

ii) Alcohol-in-glass thermometer

iii) Constant volume gas thermometer

iv) Bimetalic thermometer

v) Thermocouple

vi) Resistance thermometer

vii) Optical pyrometer

viii) Total radiation pyrometer

ix) Speed of sound

x) Thermodynamic

In general medicine, mercury-in-glass and alcohol-in-glass thermometers are usually used. In addition, thermocouple and thermistors are used in electronic thermometer.

5.3. NTC TYPE THERMISTORS

In this device, NTC type thermistor is used. Now, we may see, how to use a NTC and what is its special property. NTC thermistors are resistors with a high negative temperature coefficient of resistance. They are prepared from oxides of the iron group of transition elements, e.g., Cr, Mn, Fe, Co, or Ni. These oxides have a high resistivity in the pure state, but can be transformed into semiconductors by adding small amounts of foreign ions which have different valency. It can be explained with an example. Iron oxide Fe_2O_3 where 2 small parts of the Fe^{+3} ions are replaced by Ti^{4+} ions. These Ti^{+4} ions are compensated by an equal amount of Fe^{2+} ions in order to maintain electroneutrality. At low temperatures the extra electrons of the Fe^{+2} ions are situated on Fe ions next to the Ti^{+4} ions but at higher temperatures they are gradually loosened from these sites and contribute to the conductivity. In this case we obtain an electron or n-type semiconductor.

We know that the conductivity σ of the materials can be generally described by,

$$\sigma = ne\,\mu$$

where e represents the unit of electric charge and n and μ the concentration and the mobility of the charge carriers respectively. Both n and μ depend on temperature. For n, this dependence is an exponential one, according to a Boltzman law.

$$n \sim e^{-q_1/kT}$$

or

$$n = K\,e^{-q_1/kT}$$

where q_1 is related to the electrostatic binding energy of the carriers to the foreign ions.

We can write the temperature dependence of μ as follows:

$$\mu = K e^{-q_2/kT}$$

where q_2 is thermal activation energy for each group to neighbor side.

The total temperature dependence of conductivity is generally proportional to:

$$\sigma = K e^{-(q_1+q_2)/kT}$$

So that, the resistance variation of the thermistor can be represented by the simple formula:

$$R = A e^{B/T}$$

5.4. DESIGN IMPLEMENTATION

Now, we would like to explain how we designed the thermometer part of our instrument. We have measured heart rate with the monostable 74121 which gives us a pulse whose width is proportional to heart rate. If we want to measure the temperature by adding minimal amount of components, we have to use the same principle. Thus, if we use the same principle we obtain a pulse whose width is proportional with temperature. We have had a counter which counts the pulse length of heart rate. If we use the same principle that means, if we obtain a pulse whose length is proportional to the temperature, we can measure the length of this pulse using the same counter. That means, we have to use monostable 74121.

We have known that this monostable gives us a pulse whose width changes with external resistance and capacitance. If we use thermistor instead of external R resistance, the output pulse of monostable changes with temperature. There are two important problems to measure the temperature using the monostable 74121. The first one, the output pulse 74121 changes with ambient temperature and supply voltage. The second problem is the reverse relation between the output pulse of 74121 and the thermistor temperature. It means that, if the temperature of thermistor increases, the output pulse of 74121 decreases. If the temperature of the thermistor decreases the output pulse of 74121 increases. These two problems can be solved by adding a monostable which gives us a fixed pulse. If we subtract the first pulse from the fixed pulse, we obtain a pulse whose length is proportional to the temperature. And we can see that if the pulse width of 74121 changes with supply voltage and ambient temperature two monostables are also influenced from voltage and ambient temperature. Voltage effects of monostables cancel each other, if supply voltage of monostables changes, and also if ambient tmeperature changes, this effect is canceled by two monostables. Now we can see how we measure temperature. The circuit diagram is shown in Figure 23.

We have seen, the circuit consists of two 74121 and one 7408. (Quad-2-input AND gate)

If we say that the pulse width of monostables outputs are t_i. The output pulse of the second monostable is t_1 which depends on thermistor temperature. The output pulse of the second monostable is t_2 which is fixed. t_2 is bigger than t_1 and if we subtract t_1 from t_2, we obtain τ whose length gives us thermistor temperature in µsec.

$$\tau = t_2 - t_1$$

Our thermistor can be formulated by using its temperature dependence which is shown in Figure 24.

$$\frac{44-32}{6-4} = \frac{44 - T}{R - 4}$$

And we can write R,

$$R_{therm} = \frac{1}{6} (68 - T) \; k\Omega$$

Now, we have to obtain a pulse whose length is equal to thermistor temperature. Our temperature-to-pulse length converter, can be adjusted with R and C. There are two pulse which are t_2 and t_1. t_2 is a constant pulse and it is bigger than t_1 . t_1 is proportional to T°C. We can write these dependence,

$$\tau = t_2 - t_1 \ \mu\text{sec}$$

$$T_2 = 0.7 \ RC = a \ \mu\text{sec}$$

$$T_1 = 0.7 \ (R_{therm} + R_1) \ C_1$$

$$\tau = 0.7 \ RC - 0.7 \ (R_{therm} + R_1) \ C_1$$

$$\tau = a - 0.7 \ R_{therm} \ C_1 - \underbrace{0.7 \ R_1 \ C_1}_{b}$$

$$\tau = a - b - 0.7 \ R_{therm} \ C_1$$

τ must be 320 μsec at 32°C and 440 μsec at 44°C. If we subtract τ_{44} from τ_{32}

$$\tau_{44} - \tau_{32} = C - 0.7R_{44}C_1 - (C-0.7R_{32}C_1)$$

$$120 \ \mu\text{sec} = 0.7(R_{32} - R_{44}) \ C_1$$

We have known that $R_{32} = 6k\Omega$ and $R_{44} = 4k\Omega$.

$$120\ \mu sec = 0.7 \cdot 2000 \cdot C_1$$

$$C_1 = \frac{120.10^{-6}}{1400} = 0.085\ \mu F$$

Now, we can calculate t_1 and t_2 $R_1 = 6.8\ k\ \Omega$

$$t_1 = 0.7\ (R_{therm} + R_1)\ C_1$$

$$t_{32} = 0.7\ (6.8 + 6)\ 0.085 \cdot 10^{-3}$$

$$= 76.10^{-5} = 760\ \mu\ sec$$

$$t_{44} = 0.71\ (6.8 + 4)\ 0.085 \cdot 10^{-3}$$

$$= 640\ \mu sec$$

at $32^{o}C$, τ must be 320 μsec.

$$\tau = t_2 - t_{32}$$

$$320 = t_2 - 760 \rightarrow t_2 = 1080\ \mu sec$$

at $44^{o}C$, τ must be 440 μsec.

$$\tau = t_2' - t_{44}$$

$$440 = t_2 - 640 \rightarrow t_2 = 1080\ \mu sec.$$

We can adjust t_2 as 1080 sec with R and C.

5.5. ACCURACY OF THERMOMETER

The accuracy of the pulse width depends on the following reasons in a digital thermometer.

i) Accuracy of thermistor resistance
ii) Accuracy of timing capacitance
iii) Linearity of thermistor characteristics
iv) Voltage dependence of 74121
v) Linearity of 74121
vi) Ambient temperature dependence of 74121
vii) Power to dissipiated factor of thermistor.

Our pulse width relation was,

$$\tau = t_2 - t_1$$

We can say that the conditions (iv) and (vi) which change pulse width changes

$$t_1 \rightarrow t_1 + \Delta t_1 \ ; \quad t_2 \rightarrow t_2 + \Delta t_2$$

If we write pulse width relation,

$$\tau = t_2 + \Delta t_2 - (t_1 + \Delta t_1)$$

Δt_1 and Δt_2 are approximately equal because of two monostables have the same conditions.

$$\Delta t_1 \cong \Delta t_2$$

$$\tau = t_2 - t_1$$

We have seen that conditions (iv) and (vi) are not important for us.

We have worked in a narrow band for thermistor and monostable, so we can think that monostable and thermistor work linearly in this band. This implies that conditions (iii) and (v) can be solved. Problems (i) and (ii) can be solved by using the best quality components. Now there is an interesting problem. This is the power dissipation of thermistor. In our circuit, current passes through the thermistor for less than 1 μ sec in every 2 sec. Now we can say that if we use ceramic capacitance and an accurate thermistor, our circuit works linearly and it works accurately.

CHAPTER 6

ALARM CIRCUITS

We have four alarms. These are low and high heart rate alarms and low and high temperature alarms. These four alarms were constructed with the same principle as we mentioned in Chapter 5, Section 4. We measure heart rate and temperature with pulse width. Also alarms can be set with pulse width. This is a very easy process. For this process, we use four 74121, two of them for the heart rate alarms and the others for the temperature alarms.

6.1. HEART RATE ALARAMS

We have known that we had measured heart rate beat-to-beat and at the end of interval V.C.M gives us a pulse whose width equals heart rate in microseconds. If we use two monostables and trigger them with short monostable (which triggers V.C.M) we obtain two pulses as the output of them. These two pulses can be adjusted by resistance (R) which is connected to pin 11 of 74121. And these pulses can be compared to the V.C.M. pulse. This comparison can be made by AND and OR gates.

6.1.1. Low Alarm

74121 has both positive and negative going output pulses. For low alarm, we multiply the negative going output of VCM and the positive going output of low alarm monostable. We adjust low-alarm monostable to give a pulse whose length is low alarm value in µsec. This adjustment can be seen from displays. Thus, our counter can count and displays digitally every pulse which comes from 74121. Figure 25 shows us the pulse shape and how we obtain alarm pulse. If the output pulse of VCM is shorter than the output of low alarm monostable, the output of AND gate gives us a pulse.

6.1.2. High Alarm

For high alarm, we multiply the positive going output of VCM and the negative going output of high alarm monostable. High alarm monostable gives us a pulse whose width is high alarm value in µsec.

This pulse width can also be seen from displays.

If the output pulse of VCM is longer than the output of high alarm monostable, the output of AND gate gives us a pulse.

Alarm pulses which come from low or high alarm circuits are set to the OR gate. The output of OR gate triggers a monostable (M_{alarm}) whose pulse width is fixed. This fixed pulses could start the alarm as soon as heart rate goes out of set limits. But this is not a good procedure, because sometimes in normal conditions, heart may go out of these limits, this abnormality continues two or three pulses then the heart returns to the healthy state. This implies that we have to use a delay circuit. This circuit must work as follows:

i) 6 or more back to back alarm pulses have to start alarm

ii) 2 or 3 back to back alarm pulses do not have to start alarm

iii) Some abnormalities which are shorter than 6 beats must fire alarm, if these abnormalities occur frequently.

These conditions are obtained easily with the alarm delay circuit which is explained as follows.

6.1.3. Alarm Delay Circuit

Alarm delay circuit is shown in Figure 25. As we have seen, delay circuit consists of a current source and a capacitance (C_1). Every alarm pulse charges C_1 and R_1 decharges C_1. If 6 or more alarm beats are coming, C_1 charges and the voltage of C_1 decreases under 4 volts. The voltage comparator is fired when the voltage of C_1 is lower than 5 volts. And the alarm starts. If heart works abnormally, there will be alarm signals which will not come sequentially These signals will also fire the alarm. Thus, the capacity discharges slowly and charges quickly.

6.2. TEMPERATURE ALARM

The principle of the temperature alarm circuit has the same principle of heart rate alarm circuit.

CHAPTER 7

POWER SUPPLY

7.1. SAFETY

In the medical instrumentation field, we have recognized the need for improved safety standards for medical equipment of all types. We have to establish quick lines of safety to protect both the patients and personnel. Because, current higher than the safety level can cause immediate death. Now, we will look how much current makes one feel uncomfortable, what causes death, etc.

The threshold of perception of shock varies widely from person to person, it is about 1 miliampere. At this level, a faint tingling sensation is felt. At current levels of around 5 miliamperes, many sensory nerves are stimulated and the sensation becomes painful, usually to the point that the subject jumps away from the source of stimulation. At current levels higher than 5 miliamperes, motor nerves are stimulated and the associated muscles contract. At the so called "let go" current level, (approximately 10 to 20 miliamperes) a person can just manage to release his grip on conductors supplying current. From 20 miliamperes to approximately 100 miliamperes, the subject has no ability to control his own muscle actions and he is unable to release his grip on the electrical conductor. The electrical current stimulation becomes increasingly painful and physical injury may result by the powerful contraction of the skeletal muscles. Despite pain and fatigue, the heart and respiratory functions usually continue since the current spreads uniformly through the trunk of the body and tends to bypass the heart as it makes up a relatively small part of the cross-sectional area of the human trunk. At about 100 miliamperes, more life-threatening physiological phenomena can occur, and ventricular fibraillation starts. Continuous high current levels of 6 Amperes or high density of 6 Amperes are very dangerous. This level may cause burns and also death.

From many investigations conducted over the years 5 miliamperes has become accepted as the maximum current that should be allowed to pass through a human from external contact.

All figures which are given above, are taken in normal conditions; but, if we measure heart rate, the electrodes are located with the paste which reduces the instrument's electrodes-to-patient skin resistance, and because of the location, all current passes through the heart. In these conditions, ventricular fibrillation could be produced by currents as small as 20 microamperes. Because of this reason we have to take 10 microamperes as the upper limits.

Now, we have known that we have to prevent the passage of the current through the body. We have two ways to achieve safety.

1. Grounding
2. Isolation

1. All (circuits) in the equipment must be grounded, also we should use a good second ground for safety. If the first grounding is broken, second wire grounds leakage currents.
2. Isolation can be made by an isolation transformer.

Isolation

In our circuit, patient and instrument power supply are isolated. This isolation is made by DC-to-DC converter operating at high frequency.

The push-pull dc-dc converter is actually a free running oscillator that produces an unregulated square wave output. The dc input is chopped into complementary square waves, passed through a transformer, then rectified and filtered. Preamplifier which amplifies ECG signals is fed by the dc-to-dc converter (or isolated power supply).

7.2. ISOLATED POWER SUPPLY

In our circuit, 15 volts which comes from the transformer is rectified and is chopped. Chopper circuit consits of two ICs (7404 and 7476). We obtained 25kHz from 7404 and this 25 kHz drives the clock of 7476. The output of 7476 gives us a square wave. The reason of using 7476 is to obtain an exact square wave. If we can not obtain exact square wave, one of the transistors which chops 15 volt gets hotter than the other because it conducts more than the other. Square wave which comes from 7476 drives BC237 and the output of BC237 drives BD139 which choppes 15 volts. That means, the transistor BD139 is driven on and off through its base terminal by a pulse train whose duty cycle is one. 7476 has two outputs, one of them is inverse of the other. Because of this reason, when one of the BD139 is ON, the other is OFF, and we obtain a square wave. This square wave passes through a transformer, then rectified and filtered. Complete circuit diagram is shown in Figure 26. In this circuit, the most important problem is finding N. N can be found by,

$$N = \frac{U}{4.44.f.\phi}$$

$$f = 25.000 \text{ Hz}$$

$$\phi = B.S; \quad S = 1.7 \text{ cm}^2$$

$$N = \frac{15}{4.44x25.10^3 \text{ x } 1.7x10^{-4} \cdot 2000 \text{ x } 10^{-4}}$$

$$= \frac{15}{4.44x25x1.7 \cdot 2} \cdot 100 = 7.85 \text{ turns}$$

We can take 8 turns.

At the output of the transformer, we want to obtain ∓ 15 volt. The output windings are calculated to give ∓ 18 volts. Then this output is rectified and regulated to obtain ∓ 15 volt. We have to use a filter at the output of the supply. This filter is a simple one which consists of 100μF and 39Ω.

CHAPTER 8

CLINICAL SIGNIFICANCE

8.1. HEART RATE

In counting heart rate, there are two measuring systems. One way is to feel pulse and the other is the ECG. The first way may cause us to make a mistake Because, all of the heart beats may not be conducted to the pulse.

The normal values of the heart rate are:

in adults - 60 - 90 beats/min
in children - 80 - 110 beats/min
in new born - 100 - 120 beats/min

Heart beats are controlled by the autonom nerve system, and the other systems that affect this are; the peripheric vascular resistance, adrenargic activity and the local metabolic factors.

Cardiac output depends on two factors; one is the heart rate, the other is the beat volume. In acute changing, the heart rate; in chronics the heart volume is important and effective to make the cardiac output constant.

This compensation mechanism is for a normal person. In persons whose heart rate is pathologic it differs.

These abnormal cardiac rhythms can be summarized as follows:

Regular Sinus Rhythm

This is the normal rhythm of the heart. The average rate is 60-100 beats/min.

Sinus Tachycardia

A regular sinus rhythm with a rate in excess of 100. Sinus tachycardia does not usually exceed 160 beats/min in the adult.

Sinus Bradycardia

A regular sinus rhythm, a rate under 60 beats/ min.

Sinus Arryhtmia

The impulse arises normally in the SA node. The arrhytmia is manifested by alternating periods of slower and more rapid heart rates. The variations are usually related to respiration, the rate increasing with inspiration and decreasing with expiration. This condition is more common in children than adults and frequently associated with sinus bradycardia.

Sinus Arrestcardiac Standstill

This denotes apause in the cardiac rhythm due to a momentary failure of the sinus node to initiate an imulse. This results in a prolonged diastolic pause between two complexes. Usually only a single beat is dropped at a time.

8.2. TEMPERATURE

The factor which causes an elevation temperature is Endotoxin which causes to release fever producing substances into the circulation from the Leukocytes. These substances which have been called endogenous pyrogens are presumabely factors which act on the thermoregulartory centers to produce fever.

The endotoxins which are pyrogenic are some bacteria and a few viruses.

In general, it is safe to regard an oral temperature above 37.2°C in a person at bed rest as an indication of disease. The temperature may be as low as 33.8°C in healthy persons. Rectal temperature is usually 1° - 0.5°F higher than oral temperature.

Deviations of 5°F (approx. 3.5°C) from the normal body temperature do not interfere appreciably with most bodily functions. Convulsions are common at temperatures higher than 41.1°C and irreversible brain damage, presumably due to protein denaturation is common when temperatures of 42.2°C are reached. Fortunately when hyperthermia reaches dangerous levels, the mechanisms for heat loss are suddenly activated; consequently oral temperatures above (41.1°C) are rare in man. Conversely, when temperatures are lowered to 32.8°C loss of consciousness occurs, and between 83 and 84°F (32.8°C) slow atrial fibrillation supervenes.

The systemic symptoms accompanying deviations in temperature are poorly understood. For example, at temperatures of 102°F (39°) many patients have malaise, drowsiness, weakness and generalized aches and pains. Many other, however, feel entirely well. Heat pyrexia is most common in individuals with pre-existing cronic disease. These patients usually stop sweating according to an intrinsic breakdown of the heat regulatory mechanism for reasons not known. In these internal body temperatures as high as 44.4°C have been reached.

Hypothermia is far less common than is elevation in temperature, but is of considerable importance because it represents a medical emergency which lends itself to treatment. The diagnosis of hypothermia has proved elusive largely because clinical thermometers do not record temperatures below 35°C but our device can give us a chance to record below 35°C.

Patients with temperatures less than 26.7°C are usually unconscious. One young patient was saved even after her temperature dropped to 20.6°C.

In many illnesses fever is the most prominent and often the only manifestation of disease. There are four types of fever.

i) An intermittent fever is one in which the temperature falls to normal each day.
ii) In remittent fever, the temperature falls each day, but does not return to normal.
iii) A sustained fever is characterized by persistent elevation without significant daily variation.
iv) A relapsing fever is one in which short ferrile periods occur between one or several days of normal temperature.

As indicated above, small variations of fever is not so important, but the daily changes and its persistency are important.

CHAPTER 9

CLINICAL TESTING

9.1 TESTING THE HEART RATE MONITOR

For testing the heart rate monitor, the pulses obtained from ECG simulator were applied instead of human heart beats. This instrument has an operating range of 40 to 200 beats/min with an accuracy of $\mp$ 5%. The curve of error shows linear character between 40 beats/min and 200 beats/min. At 40 beats/min, the error is - 5% and at 200 beats/min, it is + 5%.

9.2. TESTING CLINICAL THERMOMETER

For testing the clinical thermometer, we have measured oral temperature, but this measurement did not give us an exact value. Different parts of the mouth gave us different values. If we test our instrument with different cups that are filled with water which have different temperatures, test results can be obtained easily. This result gave us $\mp$ 2% error. This error depends on using 0.075 μF instead of 0.085 μF in thermometer design. (Figure 23)

CHAPTER 10

10.1. FURTHER IMPROVEMENTS

An instrument of this type can not be perfected at the first prototype. Additional improvements are desired in the future developmental prototypes.

The most important of these are:

1. Isolation circuit power output increase
2. Temperature measurement circuit accuracy improvement.

In this device, isolation transformer is used only for amplifier section. But, isolation circuit has to be designed for all circuit isolation. If there are some changes in the isolation circuit (for example, if 2N3055 is used instead of BD139) it can beed all circuits easily.

Secondly, for temperature measurement, we have used two separate 74121 to obtain temperature-to-pulse width conversion.

If 74123 is used instead of two 74121 temperature measurement would be much more accurate. Due to unavailability of 74123 in the market, we could not use this approach.

10.2. COST DETERMINATION

System used for Cost Determination

The basic procedures for determining manufacturing costs are the same and are classified as;

a. Job order cost accounting
b. Process cost accounting

Our procedure for determination of cost is Job order cost accounting. With Job order costing, costs are accumulated on the basis of specific jobs, batches or customer orders and generally used by custom manufacturers. Additionally, the units produced in one batch may differ with respect to styles, qualities, finish and other characteristics from the units produced in another batch.

Cost determination may be on a;

a. Historical basis, or,

b. Predetermined basis

Our cost determination is not a historical basis, because costs are accumulated as they occur and used as being the actual data for the cost accouting system.

Our cost determination is on a predetermined basis. That means, costs are predetermined in advance of production. Variation from the predetermined costs are accumulated in separate accounts so that the management will be able to make plans and adjustments in operations.

If there is cost of rework on units, it is treated as spoilage:

- Ignore spoilage: can be used only if determination is made at the end of production
- Otherwise, compute spoilage separately.

We ignore spoilage.

If we want to produce 100 units of Heart Rate Meter and Clinical thermometer in one year.

The possible expenses would be in

1. Circuit component and parts
2. Auxiliary material
3. Labor costs

4. Depreciation
5. Manufacturing Overhead
6. Service Costs

CIRCUIT COMPONENTS

Quantity	Description	Price
13	SN74121	390.00
9	SN72741	315.00
4	SN7490	160.00
3	SN 7447	210.00
2	SN7400	30.00
2	SN7404	30.00
1	SN7408	15.00
1	SN7432	25.00
1	SN7476	30.00
12	Various Transistors	90.00
7	BD135	140.00
1	2N3055	40.00
1	10MHz Crystal	390.00
5	Various Capacitors	250.00
7	Various Potentiometers	100.00
2	Transformer	220.00
9	Socket	270.00
1	Comutator	100.00
1	32-way connector	100.00
3	6-way connector	75.00
1	Thermistor	100.00
		3080.00 TL

The price of 100 units = 3080 x 100 308,000.00 TL

AUXILARY MATERIAL 100,000.00

LABOR COSTS

3 x 10,000 x 12 360,000.00 TL

DEPRECIATION

The price of equipment	150,000.00	
The price of equipment after 10 years	50,000.00	
	100,000.00	
$= \frac{100,000}{10 \text{ years}}$		10,000.00 TL

MANUFACTURING OVERHEAD

Insurance	6,000.00	
Repairs and Maintanence	24,000.00	
Rent	60,000.00	
Factory expenses	10,000.00	
		100,000.00
SERVICE COSTS		60,000.00
	TOTAL	938,000.00 TL

The price of one unit $= \frac{\text{TOTAL}}{100}$ 9,380.00 TL

10.3. DISCUSSION AND CONCLUSION

In this study, a heart rate monitor and clinical thermometer has been designed. These instruments are generally used in hospitals, and each patient needs such an instrument. Because of this reason, it had to be cheap. This condition is satisfied. We can not obtain more sensitive instrument because of using low cost components and simplicity. But, this sensitivity is enough for us, thus we will use this instrument as a bedside unit. This instrument is created with a monostable 74121. 74121 is used in the heart rate monitor and in the clinical thermometer as a main component. Data books say that 74121 works linearly in a fixed region, but we saw that it does not exactly work linearly in these regions. This pecularity brings nonlinearity. But we no not exceed the accuracy region which is given in the Abstract.

APPENDIX A

OPERATING INSTRUCTIONS

A. The heart rate monitor and clinical thermometer can be operated in the following modes:

   i) Heart-rate monitor

   ii) Thermometer

B. The front panel controls are:

   1. ON/OFF Switch

   2. Function commutator

      i) Heart rate

      ii) Heart rate minimum alarm set

      iii) Heart rate maximum alarm set

      iv) Temperature

      v) Temperature minimum alarm set

      vi) Temperature maximum alarm set

   3. Control potentiometers: These adjust lower and upper limits of the heart-rate and temperature safe ranges. There is one potentiometer for each of the following

limits.

i) Heart rate minimum

ii) Heart rate maximum

iii) Temperature minimum

vi) Temperature maximum

C. Inputs

i) Heart-rate probe

ii) Temperature probe

D. The output indicators are:

1. Display

2. Alarm indicators

i) Heart rate

ii) Temperature

E. Power connection: An 220V cable extends from the rear of the instrument.

CAUTION: The instrument can only be supplied by 220V.

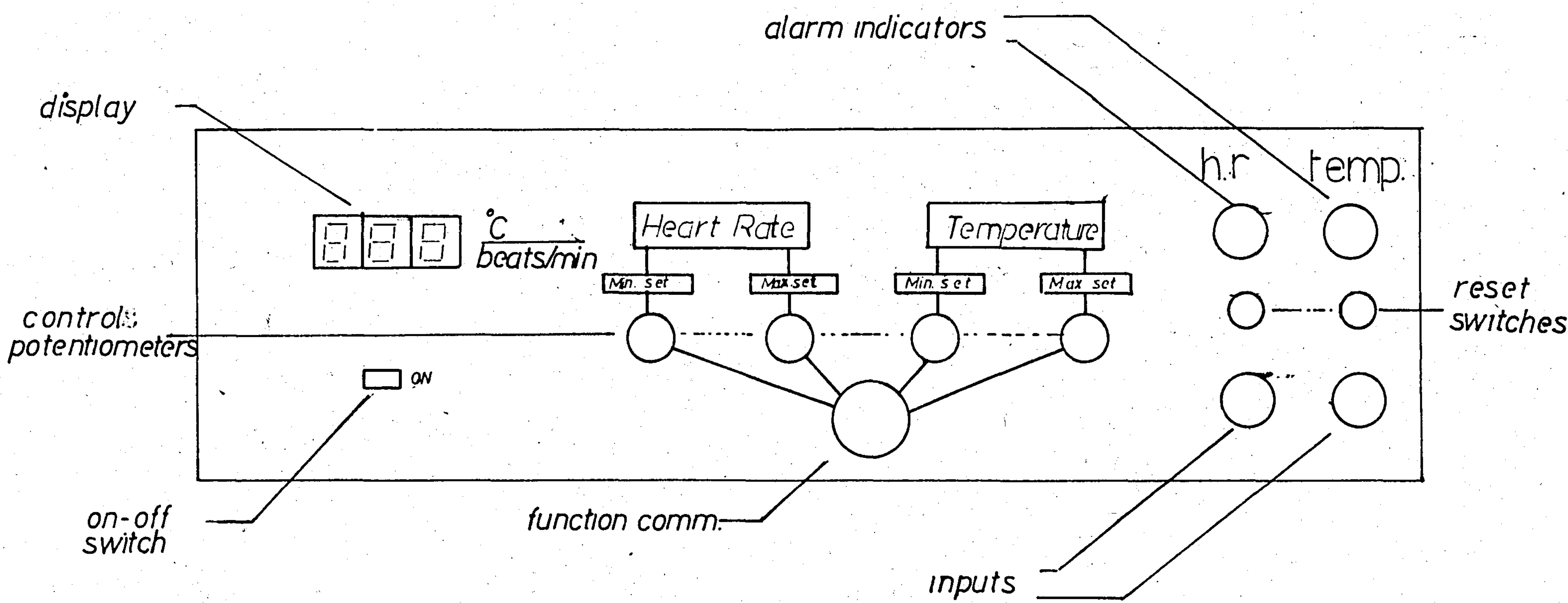


Diagram showing Front Panel of the Instrument.

APPENDIX B

- Short Circuit Protection
- Offset-Voltage Null Capability
- Large Common-Mode and Differential Voltage Ranges
- No Frequency Compensation Required
- Low Power Consumption
- No Latch-up
- Same Pin Assignments as SN52709/SN72709

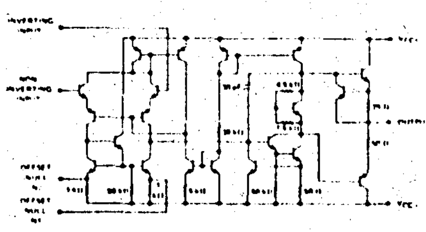
scription

The SN52741 and SN72741 are high-performance operational amplifiers, featuring offset-voltage null capability.

The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications. The devices are short-circuit protected and the internal frequency compensation ensures stability without external components. A low-value potentiometer may be connected between the offset null inputs to null out the offset voltage as shown in Figure 11.

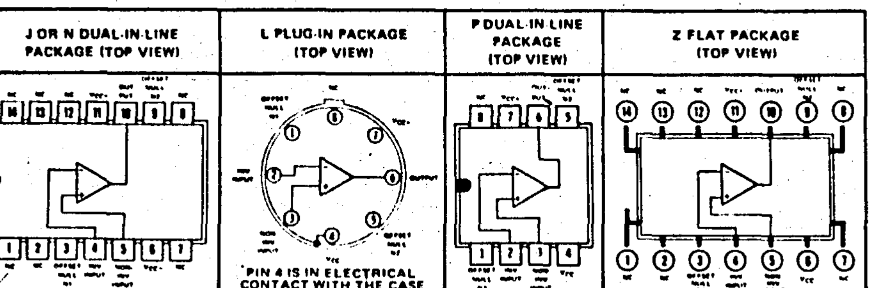
The SN52741 is characterized for operation over the full military temperature range of −55°C to 125°C; the SN72741 is characterized for operation from 0°C to 70°C.

schematic



COMPONENT VALUES SHOWN ARE NOMINAL

minal assignments



No internal connection

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

		SN52741	SN72741	UNIT
Supply voltage V_{CC+} (see Note 1)		22	18	V
Supply voltage V_{CC-} (see Note 1)		22	18	V
Differential input voltage (see Note 2)		±30	±30	V
Input voltage (either input, see Notes 1 and 3)		±15	±15	V
Voltage between either offset null terminal (N1/N2) and V_{CC-}		±0.5	±0.5	V
Duration of output short circuit (see Note 4)		unlimited	unlimited	
Continuous total power dissipation at (or below) 55°C free-air temperature (see Note 5)		500	500	mW
Operating free-air temperature range		−55 to 125	0 to 70	°C
Storage temperature range		−65 to 150	−65 to 150	°C
Lead temperature 1/16 inch from case for 60 seconds	J, L, or Z Package	300	300	°C
Lead temperature 1/16 inch from case for 10 seconds	N or P Package	260	260	°C

NOTES: 1. All voltage values, unless otherwise noted, are with respect to the zero reference level (ground) of the supply voltages where the zero reference level is the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at the noninverting input terminal with respect to the inverting input terminal.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 volts, whichever is less.
4. The output may be shorted to ground or either power supply. For the SN52741 only, the unlimited duration of the short circuit applies at (or below) 125°C case temperature or 75°C free-air temperature.
5. For operation above 55°C free-air temperature, refer to Dissipation Derating Curve, Figure 12.

electrical characteristics at specified free-air temperature, $V_{CC+} = 15$ V, $V_{CC-} = -15$ V

PARAMETER		TEST CONDITIONS†		SN52741 MIN	SN52741 TYP	SN52741 MAX	SN72741 MIN	SN72741 TYP	SN72741 MAX	UNIT
V_{IO}	Input offset voltage	$R_S \leq 10$ kΩ	25°C		1	5		1	6	mV
			Full range			6			7.5	
$\Delta V_{IO(adj)}$	Offset voltage adjust range		25°C		±15			±15		mV
I_{IO}	Input offset current		25°C		20	200		20	200	nA
			Full range			500			300	
I_{IB}	Input bias current		25°C		80	500		80	500	nA
			Full range			1500			800	
V_I	Input voltage range		25°C	±12	±13		±12	±13		V
			Full range	±12			±12			
V_{OPP}	Maximum peak-to-peak output voltage swing	$R_L \geq 10$ kΩ	25°C	24	28		24	28		V
		$R_L \geq 10$ kΩ	Full range	24			24			
		$R_L \geq 2$ kΩ	25°C	20	26		20	26		
		$R_L \geq 2$ kΩ	Full range	20			20			
A_{VD}	Large-signal differential voltage amplification	$R_L \geq 2$ kΩ,	25°C	50,000	200,000		20,000	200,000		
		$V_O = \pm 10$ V	Full range	25,000			15,000			
r_i	Input resistance		25°C	0.3	2		0.3	2		MΩ
r_o	Output resistance	$V_O = 0$ V, See Note 5	25°C		75			75		Ω
C_i	Input capacitance		25°C		1.4			1.4		pF
CMRR	Common-mode rejection ratio	$R_S \leq 10$ kΩ	25°C	70	90		70	90		dB
			Full range	70			70			
$\Delta V_{IO}/\Delta V_{CC}$	Power supply sensitivity	$R_S \leq 10$ kΩ	25°C		30	150		30	150	μV/V
			Full range			150			150	
I_{OS}	Short-circuit output current		25°C		±25	±40		±25	±40	mA
I_{CC}	Supply current	No load,	25°C		1.7	2.8		1.7	2.8	mA
		No signal	Full range			3.3			3.3	
P_D	Total power dissipation	No load,	25°C		50	85		50	85	mW
		No signal	Full range			100			100	

†All characteristics are specified under open loop operation. Full range for SN52741 is −55°C to 125°C and for SN72741 is 0°C to 70°C.
NOTE 5: This typical value applies only at frequencies above a few hundred hertz because of the effects of drift and thermal feedback.

logic

TRUTH TABLE (See Notes 1 thru 3)

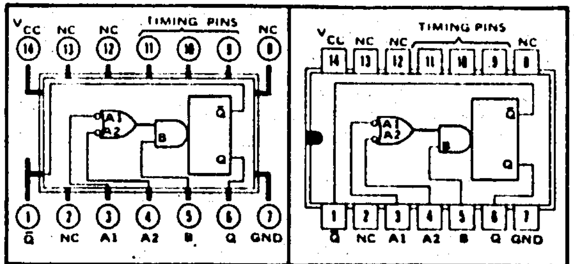
t_n INPUT			t_{n+1} INPUT			OUTPUT
A1	A2	B	A1	A2	B	
1	1	0	1	1	1	Inhibit
0	X	1	0	X	0	Inhibit
X	0	1	X	0	0	Inhibit
0	X	0	0	X	1	One Shot
X	0	0	X	0	1	One Shot
1	1	1	X	0	1	One Shot
1	1	1	0	X	1	One Shot
X	0	0	X	1	0	Inhibit
0	X	0	1	X	0	Inhibit
X	0	1	1	1	1	Inhibit
0	X	1	1	1	1	Inhibit
1	1	0	X	0	0	Inhibit
1	1	0	0	X	0	Inhibit

$1 = V_{in(1)} \geq 2$ V
$0 = V_{in(0)} \leq 0.8$ V

NOTES.
1. t_n = time before input transition.
2. t_{n+1} = time after input transition.
3. X indicates that either a logical 0 or 1 may be present.
4. NC = No Internal Connection.

W FLAT PACKAGE (TOP VIEW) (See Notes 6 thru 9)

J OR N DUAL IN LINE PACKAGE (TOP VIEW) (See Notes 6 thru 9)



positive logic: see truth table and notes 5 and 6

5. A1 and A2 are negative-edge triggered logic inputs, and will trigger the one shot when either or both go to logical 0 with B at logical 1.
6. B is a positive Schmitt trigger input for slow edges or level detection, and will trigger the one shot when B goes to logical 1 with either A1 or A2 at logical 0. (See Truth Table)
7. External timing capacitor may be connected between pin 10 (positive) and pin 11. With no external capacitance, an output pulse width of typically 30 ns is obtained.
8. To use the internal timing resistor (2 kΩ nominal), connect pin 9 to pin 14.
9. To obtain variable pulse width connect external variable resistance between pin 9 and pin 14. No external current limiting is needed.
10. For accurate repeatable pulse widths connect an external resistor between pin 11 and pin 14 with pin 9 open-circuit

description

This monolithic TTL monostable multivibrator features d-c triggering from positive or gated negative-going inputs with inhibit facility. Both positive and negative-going output pulses are provided with full fan-out to 10 normalized loads.

Pulse triggering occurs at a particular voltage level and is not directly related to the transition time of the input pulse. Schmitt-trigger input circuitry (TTL compatible and featuring temperature-independent backlash, See Figure L) for the B input allows jitter-free triggering from inputs with transition times as slow as 1 volt/second, providing the circuit with an excellent noise immunity of typically 1.2 volts. A high immunity to V_{CC} noise of typically 1.5 volts is also provided by internal latching circuitry.

Once fired, the outputs are independent of further transitions on the inputs and are a function only of the timing components. Input pulses may be of any duration relative to the output pulse. Output pulse lengths may be varied from 40 nanoseconds to 40 seconds by choosing appropriate timing components. With no external timing components (i.e., pin 9 connected to pin 14, pins 10, 11 open) an output pulse of typically 30 nanoseconds is achieved which may be used as a d-c triggered reset signal. Output rise and fall times are TTL compatible and independent of pulse length.

Pulse width is achieved through internal compensation and is virtually independent of V_{CC} and temperature. In most applications, pulse stability will only be limited by the accuracy of external timing components.

CIRCUIT TYPES SN54121, SN74121
MONOSTABLE MULTIVIBRATORS

description (continued)

Jitter-free operation is maintained over the full temperature and V_{CC} range for more than six decades of timing capacitance (10 pF to 10 μF) and more than one decade of timing resistance (2 kΩ to 40 kΩ). Throughout these ranges, pulse width is defined by the relationship $t_{p(out)} = C_T R_T \log_e 2$.

Circuit performance is achieved with a nominal power dissipation of 90 milliwatts at 5 volts (50% duty cycle) and a quiescent dissipation of typically 65 milliwatts.

Duty cycles as high as 90% are achieved when using $R_T = 40$ kΩ. Higher duty cycles are achievable if a certain amount of pulse-width jitter is allowed.

recommended operating conditions

		MIN	NOM	MAX	UNIT
Supply Voltage V_{CC}:	SN54121 Circuits	4.5	5	5.5	V
	SN74121 Circuits	4.75	5	5.25	V
Normalized Fan-Out From Each Output, N				10	
Input Pulse Rise/Fall Time:	Schmitt Input (B)			1	V/s
	Logic Inputs (A1, A2)			1	V/μs
Input Pulse Width		50			ns
External Timing Resistance Between Pins 11 and 14 (Pin 9 open)		1.4			kΩ
External Timing Resistance:	SN54121			30	kΩ
	SN74121			40	kΩ
Timing Capacitance		0		1000	μF
Output Pulse Width				40	s
Duty Cycle:	$R_T = 2$ kΩ			67%	
	$R_T = 30$ kΩ (SN54121) or $R_T = 40$ kΩ (SN74121)			90%	

electrical characteristics over operating free-air temperature range

PARAMETER		TEST FIGURE	TEST CONDITIONS†		MIN	TYP‡	MAX	UNITS
V_{T+}	Positive-going threshold voltage at A input	57	V_{CC} = MIN			1.4	2	V
V_{T-}	Negative-going threshold voltage at A input	57	V_{CC} = MIN		0.8	1.4		V
V_{T+}	Positive-going threshold voltage at B input	57	V_{CC} = MIN			1.55	2	V
V_{T-}	Negative-going threshold voltage at B input	57	V_{CC} = MIN		0.8	1.35		V
$V_{out(0)}$	Logical 0 output voltage	57	V_{CC} = MIN, I_{sink} = 16 mA			0.22	0.4	V
$V_{out(1)}$	Logical 1 output voltage	57	V_{CC} = MIN, I_{load} = −400 μA		2.4	3.3		V
$I_{in(0)}$	Logical 0 level input current at A1 or A2	58	V_{CC} = MAX, V_{in} = 0.4 V			−1	−1.6	mA
$I_{in(0)}$	Logical 0 level input current at B	59	V_{CC} = MAX, V_{in} = 0.4 V			−2	−3.2	mA
$I_{in(1)}$	Logical 1 level input current at A1 or A2	60	V_{CC} = MAX, V_{in} = 2.4 V			2	40	μA
			V_{CC} = MAX, V_{in} = 5.5 V			0.05	1	mA
$I_{in(1)}$	Logical 1 level input current at B	61	V_{CC} = MAX, V_{in} = 2.4 V			4	80	μA
			V_{CC} = MAX, V_{in} = 5.5 V			0.05	1	mA
I_{OS}	Short-circuit output current at Q or $\overline{Q}$§	62 and 63	V_{CC} = MAX	SN54121	−20	−25	−55	mA
				SN74121	−18	−25	−55	mA
I_{CC}	Power supply current in quiescent (unfired) state	64	V_{CC} = MAX			13	25	mA
I_{CC}	Power supply current in fired state	64	V_{CC} = MAX			23	40	mA

†For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions for the applicable device type.
‡All typical values are at V_{CC} = 5 V, T_A = 25°C.
§Not more than one output should be shorted at a time.

switching characteristics, V_{CC} = 5 V, T_A = 25°C

PARAMETER		TEST FIGURE	TEST CONDITIONS		MIN	TYP	MAX	UNITS
t_{pd1}	Propagation delay time to logical 1 level from B input to Q output	72	C_L = 15 pF,	C_T = 80 pF	15	35	55	ns
t_{pd1}	Propagation delay time to logical 1 level from A1/A2 inputs to Q output				25	45	70	ns
t_{pd0}	Propagation delay time to logical 0 level from B input to $\overline{Q}$ output	72	C_L = 15 pF,	C_T = 80 pF	20	40	65	ns
t_{pd0}	Propagation delay time to logical 0 level from A1/A2 inputs to $\overline{Q}$ output				30	50	80	ns
$t_{p(out)}$	Pulse width obtained using internal timing resistor	73	C_L = 15 pF, R_T = Open,	C_T = 80 pF, Pin 9 to V_{CC}	70	110	150	ns
$t_{p(out)}$	Pulse width obtained with zero timing capacitance	73	C_L = 15 pF, R_T = Open,	C_T = 0, Pin 9 to V_{CC}	20	30	50	ns
$t_{p(out)}$	Pulse width obtained using external timing resistor	73	C_L = 15 pF, R_T = 10 kΩ,	C_T = 100 pF, Pin 9 Open	600	700	800	ns
			C_L = 15 pF, R_T = 10 kΩ,	C_T = 1 μF, Pin 9 Open	6	7	8	ms
t_{hold}	Minimum duration of trigger pulse	73	C_L = 15 pF, R_T = Open,	C_T = 80 pF, Pin 9 to V_{CC}		30	50	ns

TYPICAL CHARACTERISTICS§

DISTRIBUTION OF UNITS
for
OUTPUT PULSE WIDTH

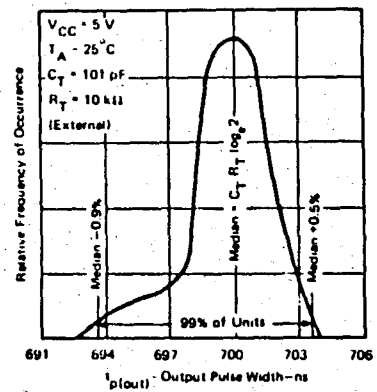


FIGURE H

VARIATION IN INTERNAL TIMING RESISTOR VALUE
vs
FREE-AIR TEMPERATURE

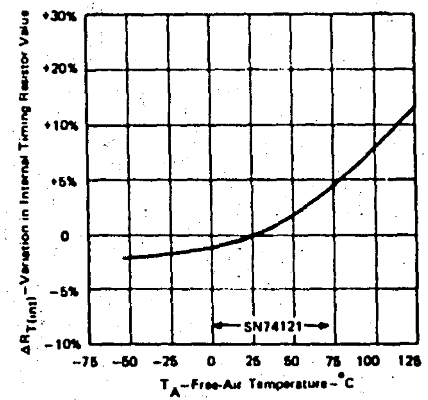


FIGURE I

VARIATION IN OUTPUT PULSE WIDTH
vs
SUPPLY VOLTAGE

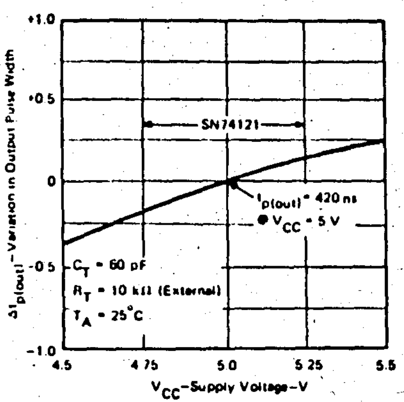


FIGURE J

VARIATION IN OUTPUT PULSE WIDTH
vs
FREE-AIR TEMPERATURE

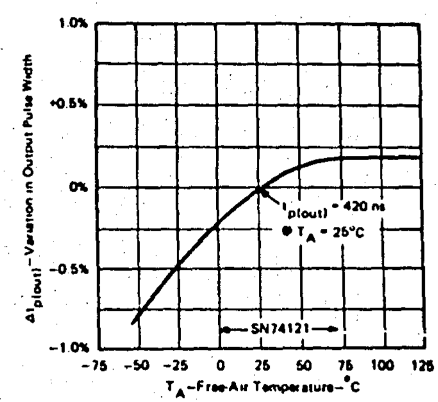


FIGURE K

§Unless otherwise noted, data is applicable for SN54121 and SN74121.

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TYPICAL CHARACTERISTICS§

SCHMITT TRIGGER THRESHOLD VOLTAGE
vs
FREE-AIR TEMPERATURE

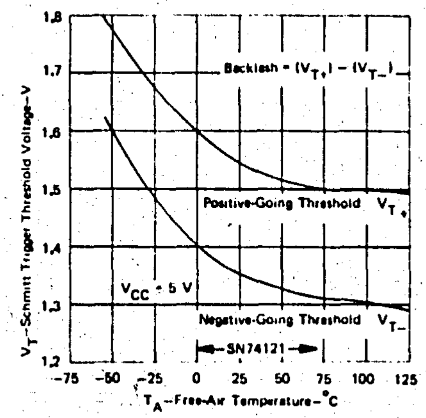

FIGURE L

PROPAGATION DELAY TIME TO LOGICAL 1 LEVEL
(B INPUT TO Q OUTPUT)
vs
FREE AIR TEMPERATURE

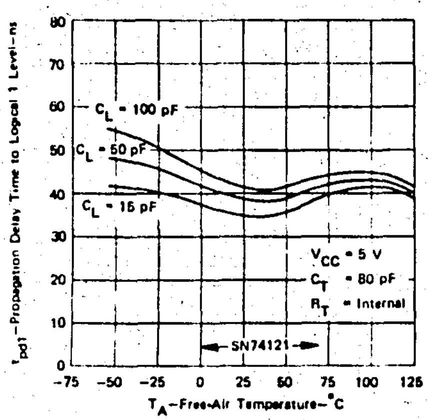

FIGURE M

PROPAGATION DELAY TIME TO LOGICAL 0 LEVEL
(B INPUT TO $\overline{Q}$ OUTPUT)
vs
FREE-AIR TEMPERATURE

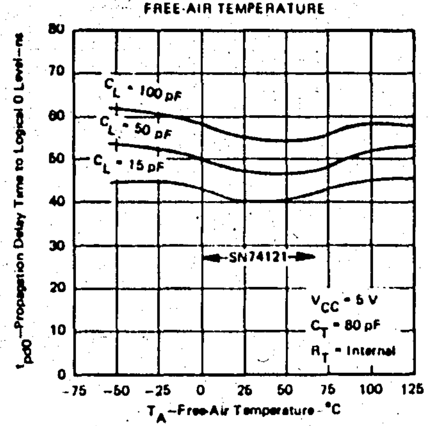

FIGURE N

§Unless otherwise noted data is applicable for SN54121 and SN74121.

TYPICAL CHARACTERISTICS§

OUTPUT PULSE WIDTH
vs
TIMING RESISTOR VALUE

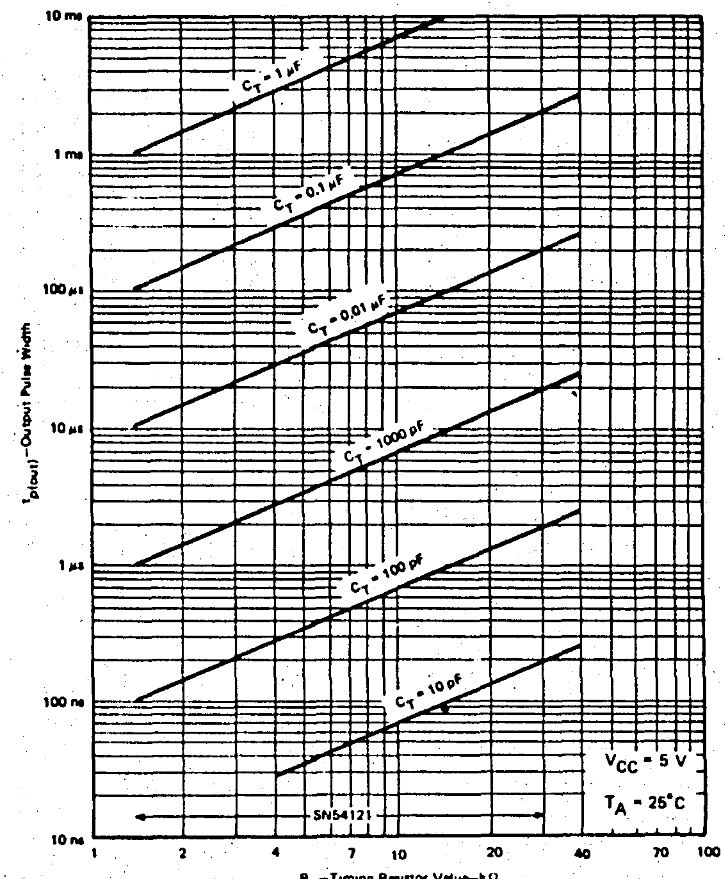

FIGURE O

§Unless otherwise noted data is applicable for SN54121 and SN74121.

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TYPICAL CHARACTERISTICS §

OUTPUT PULSE WIDTH
vs
EXTERNAL CAPACITANCE

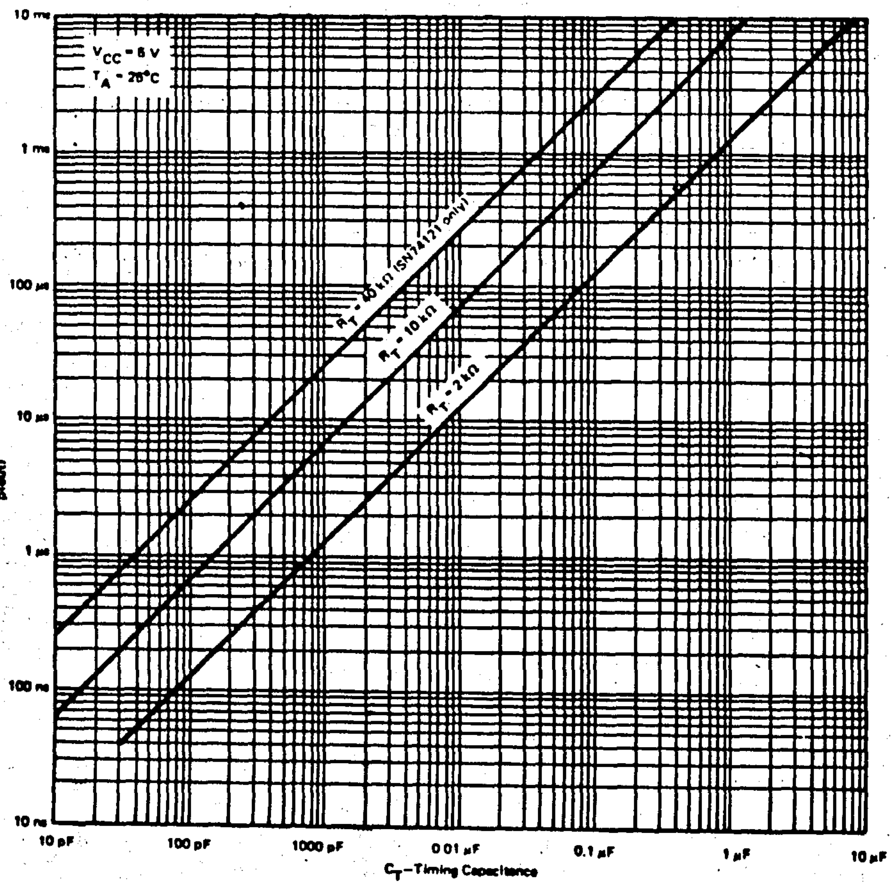


FIGURE P

§ ...ss otherwise noted data is applicable for SN54121 and SN74121.

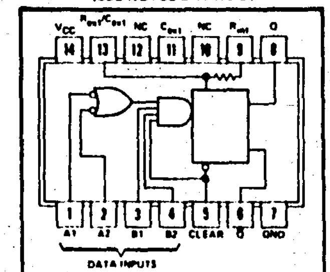
- Retriggerable for Very Long Output Pulses, Up to 100% Duty Cycle
- Overriding Clear Terminates Output Pulse
- Diode-Clamped Inputs
- D-C Triggered from High- or Low-Level Gated Logic Inputs
- Compatible for Use with TTL or DTL
- Typical Average Propagation Delay to Output Q . . . 21 ns

logic

SN54122, SN74122
TRUTH TABLE
(See Note A)

INPUTS				OUTPUTS	
A1	A2	B1	B2	Q	$\bar{Q}$
H	H	X	X	L	H
X	X	L	X	L	H
X	X	X	L	L	H
L	X	H	H	L	H
L	X	↑	H	⊓	⊔
L	X	H	↑	⊓	⊔
X	L	H	H	L	H
X	L	↑	H	⊓	⊔
X	L	H	↑	⊓	⊔
H	↓	H	H	⊓	⊔
↓	↓	H	H	⊓	⊔
↓	H	H	H	⊓	⊔

SN54122, SN74122
J OR N DUAL-IN-LINE OR
W FLAT PACKAGE (TOP VIEW)†
(SEE NOTES B THRU D)

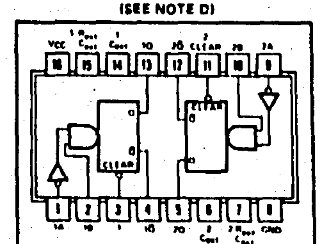


positive logic:
Low input to clear resets Q to low level and inhibits data inputs

SN54123, SN74123
TRUTH TABLE
(See Note A)

INPUTS		OUTPUTS	
A	B	Q	$\bar{Q}$
H	X	L	H
X	L	L	H
L	↑	⊓	⊔
↓	H	⊓	⊔

SN54123, SN74123
J OR N DUAL-IN-LINE OR
W FLAT PACKAGE (TOP VIEW)†
(SEE NOTE D)



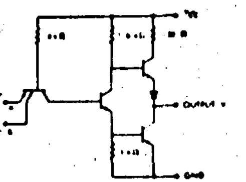
positive logic:
Low input to clear resets Q to low level and inhibits data inputs

†Pin assignments for these circuits are the same for all packages.

NOTES: A. H = high level (steady state), L = low level (steady state), ↑ = transition from low to high level, ↓ = transition from high to low level, ⊓ = one high-level pulse, ⊔ = one low-level pulse, X = irrelevant (any input, including transitions).
B. NC = No internal connection.
C. To use the internal timing resistor of SN54122/SN74122 (10 kΩ nominal), connect R_{int} to V_{CC}.
D. An external timing capacitor may be connected between C_{ext} and R_{ext}/C_{ext} (positive).

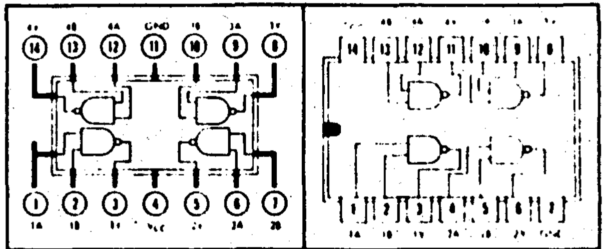
6

matic (each gate)



Component values shown are nominal.

W FLAT PACKAGE (TOP VIEW) — J OR N DUAL IN LINE PACKAGE (TOP VIEW)



positive logic: $Y = \overline{AB}$

mmended operating conditions

	MIN	NOM	MAX	UNIT
Supply Voltage V_{CC}: SN5400 Circuits	4.5	5	5.5	V
SN7400 Circuits	4.75	5	5.25	V
Normalized Fan-Out From Each Output, N			10	
Operating Free Air Temperature Range, T_A: SN5400 Circuits	55	25	125	°C
SN7400 Circuits	0	25	70	°C

ical characteristics over recommended operating free-air temperature (unless otherwise noted)

PARAMETER	TEST FIGURE	TEST CONDITIONS†		MIN	TYP‡	MAX	UNIT
) Logical 1 input voltage required at both input terminals to ensure logical 0 level at output	1			2			V
) Logical 0 input voltage required at either input terminal to ensure logical 1 level at output	2					0.8	V
1) Logical 1 output voltage	2	V_{CC} = MIN, V_{in} = 0.8 V, I_{load} = -400 μA		2.4	3.3		V
0) Logical 0 output voltage	1	V_{CC} = MIN, V_{in} = 2 V, I_{sink} = 16 mA			0.22	0.4	V
Logical 0 level input current (each input)	3	V_{CC} = MAX, V_{in} = 0.4 V				-1.6	mA
Logical 1 level input current (each input)	4	V_{CC} = MAX, V_{in} = 2.4 V				40	μA
		V_{CC} = MAX, V_{in} = 5.5 V				1	mA
Short-circuit output current§	5	V_{CC} = MAX	SN5400	20		55	mA
			SN7400	18		55	
) Logical 0 level supply current	6	V_{CC} = MAX, V_{in} = 5 V			12	22	mA
) Logical 1 level supply current	6	V_{CC} = MAX, V_{in} = 0			4	8	mA

hing characteristics, V_{CC} = 5 V, T_A = 25°C, N = 10

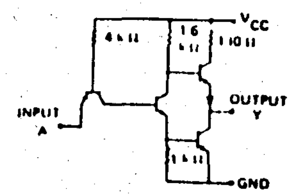
PARAMETER	TEST FIGURE	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Propagation delay time to logical 0 level	65	C_L = 15 pF, R_L = 400 Ω		7	15	ns
Propagation delay time to logical 1 level	65	C_L = 15 pF, R_L = 400 Ω		11	22	ns

nditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions for the applicable type

ical values are at V_{CC} = 5 V, T_A = 25°C

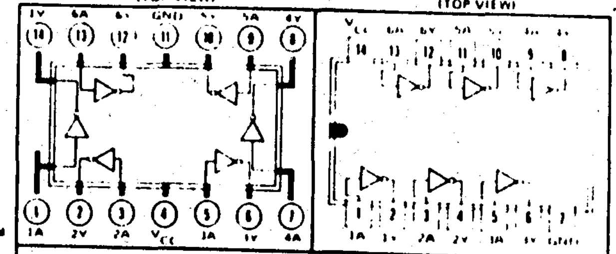
ore than one output should be shorted at a time

schematic (each inverter)



NOTE: Component values shown are nominal.

W FLAT PACKAGE (TOP VIEW) — J OR N DUAL IN LINE PACKAGE (TOP VIEW)



positive logic: $Y = \overline{A}$

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply Voltage V_{CC}: SN5404 Circuits	4.5	5	5.5	V
SN7404 Circuits	4.75	5	5.25	V
Normalized Fan-Out From Each Output, N			10	
Operating Free Air Temperature Range, T_A: SN5404 Circuits	-55	25	125	°C
SN7404 Circuits	0	25	70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST FIGURE	TEST CONDITIONS†		MIN	TYP‡	MAX	UNIT
$V_{in(1)}$	Logical 1 input voltage required at input terminal to ensure logical 0 level at output	15			2			V
$V_{in(0)}$	Logical 0 input voltage required at any input terminal to ensure logical 1 level at output	16					0.8	V
$V_{out(1)}$	Logical 1 output voltage	16	V_{CC} = MIN, V_{in} = 0.8 V, I_{load} = -400 μA		2.4	3.3		V
$V_{out(0)}$	Logical 0 output voltage	15	V_{CC} = MIN, V_{in} = 2 V, I_{sink} = 16 mA			0.22	0.4	V
$I_{in(0)}$	Logical 0 level input current	18	V_{CC} = MAX, V_{in} = 0.4 V				-1.6	mA
$I_{in(1)}$	Logical 1 level input current	18	V_{CC} = MAX, V_{in} = 2.4 V				40	μA
			V_{CC} = MAX, V_{in} = 5.5 V				1	mA
I_{OS}	Short circuit output current§	19	V_{CC} = MAX	SN5404	-20		-55	mA
				SN7404	-18		-55	
$I_{CC(0)}$	Logical 0 level supply current	20	V_{CC} = MAX, V_{in} = 5 V			18	33	mA
$I_{CC(1)}$	Logical 1 level supply current	20	V_{CC} = MAX, V_{in} = 0			6	12	mA

switching characteristics, V_{CC} = 5 V, T_A = 25°C, N = 10

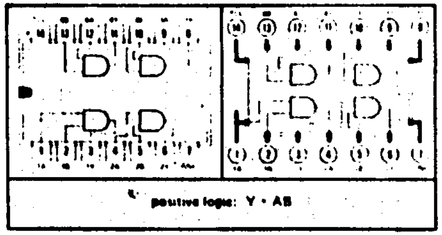
PARAMETER		TEST FIGURE	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{pd0}	Propagation delay time to logical 0 level	65	C_L = 15 pF, R_L = 400 Ω		8	15	ns
t_{pd1}	Propagation delay time to logical 1 level	65	C_L = 15 pF, R_L = 400 Ω		12	22	ns

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions for the applicable device type

‡ All typical values are at V_{CC} = 5 V, T_A = 25°C

J OR N DUAL-IN-LINE PACKAGE (TOP VIEW)

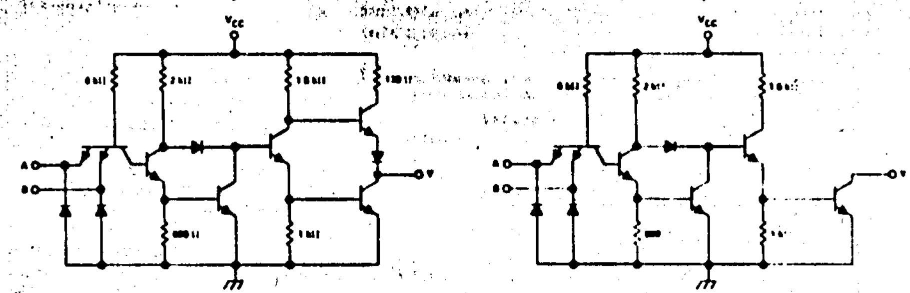
W FLAT PACKAGE (TOP VIEW)



Choice of Totem-Pole Outputs (SN5408/SN7408) or Open-Collector Outputs (SN5409/SN7409)

schematics (each gate)

SN5408, SN7408 SN5409, SN7409



Component values shown are nominal.

description

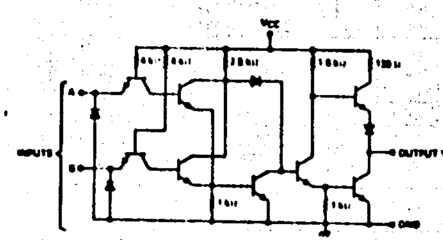
These Series 54/74 TTL gates provide the system designer with direct implementation of the positive AND or negative OR functions.

The SN5408/SN7408, with totem-pole outputs, drives 10 normalized Series 54/74 loads at the low output level and 20 loads at the high output level. The SN5409/SN7409, with open-collector output, provides additional logic flexibility, as the outputs may be wire-AND connected to extend the AND function. The SN5409/SN7409 will sink sufficient current to drive 10 normalized Series 54/74 loads at the low output level.

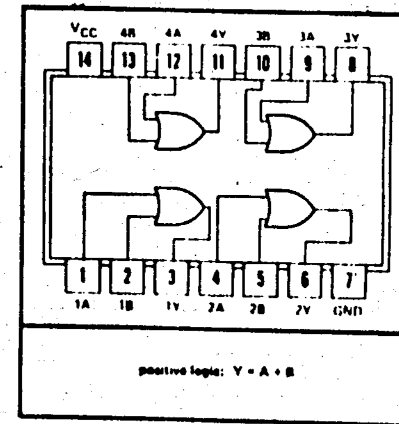
The SN5408 and SN5409 are characterized for operation over the full military temperature range of −55°C to 125°C; the SN7408 and SN7409 are characterized for operation from 0°C to 70°C.

6

schematic (each gate)



J OR N DUAL-IN-LINE OR W FLAT PACKAGE (TOP VIEW)[†]



[†]Pin assignments for these circuits are the same for all packages.

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absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC} (see Note 1)		7 V
Input voltage		5.5 V
Operating free-air temperature range:	SN5432 Circuits	−55°C to 125°C
	SN7432 Circuits	0°C to 70°C
Storage temperature range		−65°C to 150°C

NOTE 1: Voltage values are with respect to network ground terminal.

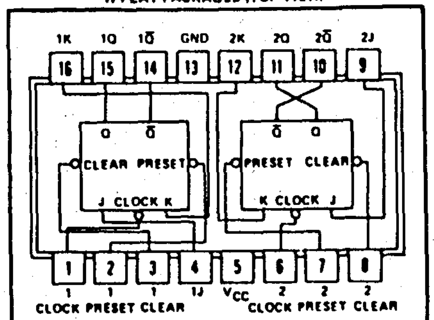
recommended operating conditions

		SN5432 MIN	SN5432 NOM	SN5432 MAX	SN7432 MIN	SN7432 NOM	SN7432 MAX	UNIT
Supply voltage, V_{CC}		4.5	5	5.5	4.75	5	5.25	V
Normalized fan-out from each output, N	High logic level			20			20	
	Low logic level			10			10	
Operating free-air temperature, T_A		−55	25	125	0	25	70	°C

TRUTH TABLE (Each Flip-Flop)		
t_n		t_{n+1}
J	K	Q
0	0	Q_n
0	1	0
1	0	1
1	1	$\overline{Q}_n$

ES: 1. t_n = Bit time before clock pulse.
2. t_{n+1} = Bit time after clock pulse.

J OR N DUAL-IN-LINE OR W FLAT PACKAGES (TOP VIEW)†



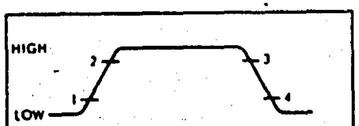
positive logic: Low input to preset sets Q to logical 1
Low input to clear sets Q to logical 0
Clear and preset are independent of clock

†Pin assignments for these circuits are the same for all packages.

ription

The SN7476 J-K flip-flop is based on the master-slave principle. Inputs to the master section are controlled by the clock pulse. The clock pulse also regulates the state of the coupling transistors which connect the master and slave sections. The sequence of operation is as follows:

1. Isolate slave from master
2. Enter information from J and K inputs to master
3. Disable J and K inputs
4. Transfer information from master to slave.



CLOCK WAVEFORM

ommended operating conditions

	MIN	NOM	MAX	UNIT
Supply Voltage V_{CC}: SN5476 Circuits	4.5	5	5.5	V
SN7476 Circuits	4.75	5	5.25	V
Operating Free-Air Temperature Range, T_A: SN5476 Circuits	−55	25	125	°C
SN7476 Circuits	0	25	70	°C
Normalized Fan-Out From Each Output, N			10	
Width of Clock Pulse, $t_{p(clock)}$ (See figure 69)	20			ns
Width of Preset Pulse, $t_{p(preset)}$ (See figure 70)	25			ns
Width of Clear Pulse, $t_{p(clear)}$ (See figure 70)	25			ns
Input Setup Time, t_{setup} (See figure 69)	$\geq t_{p(clock)}$			
Input Hold Time, t_{hold}	0			

electrical characteristics, T_A = 0°C to 70°C (unless otherwise noted)

PARAMETER		TEST FIGURE	TEST CONDITIONS†	MIN	TYP‡	MAX	UNIT
$V_{in(1)}$	Input voltage required to ensure logical 1 at any input terminal	46 and 47		2			V
$V_{in(0)}$	Input voltage required to ensure logical 0 at any input terminal	46 and 47				0.8	V
$V_{out(1)}$	Logical 1 output voltage	46	V_{CC} = MIN, I_{load} = −400 µA	2.4	3.5		V
$V_{out(0)}$	Logical 0 output voltage	47	V_{CC} = MIN, I_{sink} = 16 mA		0.22	0.4	V
$I_{in(0)}$	Logical 0 level input current at J or K	48	V_{CC} = MAX, V_{in} = 0.4 V			−1.6	mA
$I_{in(0)}$	Logical 0 level input current at clear, preset, or clock	48	V_{CC} = MAX, V_{in} = 0.4 V			−3.2	mA
$I_{in(1)}$	Logical 1 level input current at J or K	49	V_{CC} = MAX, V_{in} = 2.4 V			40	µA
			V_{CC} = MAX, V_{in} = 5.5 V			1	mA
$I_{in(1)}$	Logical 1 level input current at clear, preset, or clock	49	V_{CC} = MAX, V_{in} = 2.4 V			80	µA
			V_{CC} = MAX, V_{in} = 5.5 V			1	mA
I_{OS}	Short-circuit output current§	51	V_{CC} = MAX, V_{in} = 0, SN5476	−20		−57	mA
			V_{CC} = MAX, V_{in} = 0, SN7476	−18		−57	mA
I_{CC}	Supply current (each flip flop)	49	V_{CC} = MAX		20	40	mA

switching characteristics, V_{CC} = 5 V, T_A = 25°C, N = 10

PARAMETER		TEST FIGURE	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{max}	Maximum clock frequency	69	C_L = 15 pF, R_L = 400 Ω	15	20		MHz
t_{pd1}	Propagation delay time to logical 0 level from clear or preset to output	70	C_L = 15 pF, R_L = 400 Ω		16	25	ns
t_{pd0}	Propagation delay time to logical 1 level from clear or preset to output	70	C_L = 15 pF, R_L = 400 Ω		25	40	ns
t_{pd1}	Propagation delay time to logical 1 level from clock to output	69	C_L = 15 pF, R_L = 400 Ω	10	16	25	ns
t_{pd0}	Propagation delay time to logical 0 level from clock to output	69	C_L = 15 pF, R_L = 400 Ω	10	25	40	ns

†For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions for the applicable device type.

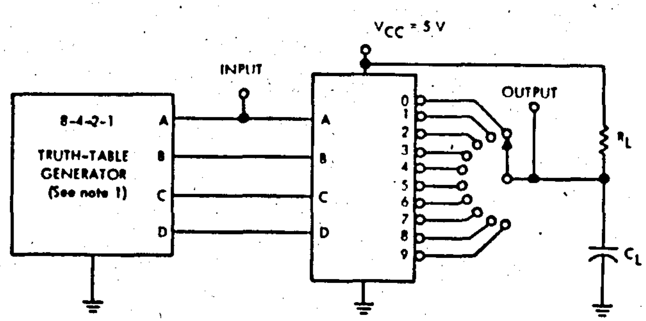
‡All typical values are at V_{CC} = 5 V, T_A = 25°C.

§Not more than one output should be shorted at a time.

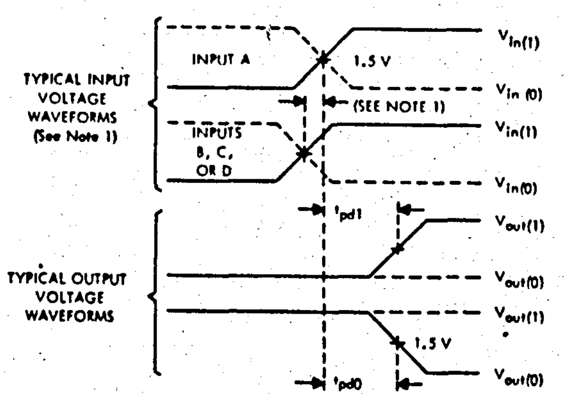
6

PARAMETER MEASUREMENT INFORMATION

switching characteristics



TEST CIRCUIT



NOTES: 1. The truth-table generator has the following characteristics: $V_{out(1)} \geq 2.4$ V, $V_{out(0)} \leq 0.4$ V, t_r and $t_f < 10$ ns, and PRR = 1 MHz. Inputs B, C, and D transitions occur simultaneously with or prior to input A transitions.

2. C_L includes probe and jig capacitance.

FIGURE 5-SWITCHING TIMES

SN5446A, SN5447A, SN7446A, SN7447A featuring

- DIRECT DRIVE FOR INDICATORS
- OPEN COLLECTOR OUTPUTS
- LAMP TEST PROVISION
- LEADING/TRAILING ZERO SUPPRESSION
- CERAMIC OR PLASTIC DUAL-IN-LINE PACKAGES

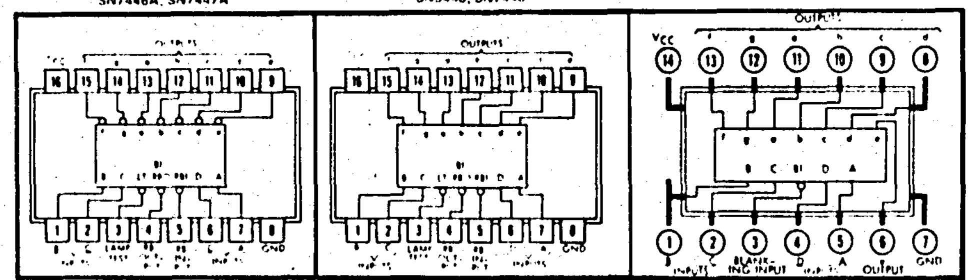
SN5448, SN7448 featuring

- PASSIVE PULL-UP OUTPUTS
- LAMP TEST PROVISION
- LEADING/TRAILING ZERO SUPPRESSION
- CERAMIC OR PLASTIC DUAL-IN-LINE PACKAGES

SN5449, SN7449 featuring

- OPEN COLLECTOR OUTPUTS
- BLANKING INPUT
- WELDED FLAT PACKAGE

J OR N DUAL-IN-LINE OR W FLAT PACKAGE (TOP VIEW)†
SN5446A, SN5447A, SN7446A, SN7447A — SN5448, SN7448 — SN5449, SN7449 W FLAT PACKAGE (TOP VIEW)



positive logic: see truth tables

†Pin assignments for these circuits are the same for all packages.

ALL CIRCUIT TYPES FEATURE:

- TTL-DTL COMPATIBILITY
- FULL DECODING OF ALL 16 INPUT COMBINATIONS
- LAMP INTENSITY MODULATION CAPABILITY

description

These monolithic, TTL, BCD-to-seven-segment decoder/drivers consist of NAND gates, input buffers, and seven AND-OR-INVERT gates. Three configurations offer active-low, high-sink-current outputs (SN5446A and SN5447A) for driving indicators directly; active-high, passive-pull-up outputs, (SN5448) and active-high, open-collector outputs (SN5449) for current-sourcing applications to drive logic circuits or discrete, active components. Seven NAND gates and one driver are connected in pairs to make BCD data and its complement available to the seven decoding AND-OR-INVERT gates, and the remaining NAND gate and three input buffers provide lamp test, blanking input/ripple-blanking output, and ripple-blanking input for the SN5446A, SN5447A and SN5448. Four NAND gates and four input buffers provide BCD data and its complement and a buffer provides blanking input for the SN5449. See functional block diagrams.

The circuits accept 4-bit binary-coded decimal (BCD) and, depending on the state of the auxiliary inputs, decodes this data to drive a seven-segment display indicator (SN5446A and SN5447A) or other components (SN5448, SN5449). The relative positive-logic output levels, as well as conditions required at the auxiliary inputs, are shown in the truth tables. Output configurations of the SN5446A and SN5447A are designed to withstand the relatively high voltages required for seven-segment indicators. The SN5446A outputs will withstand 30 volts, and the SN5447A will withstand 15 volts, with a maximum reverse current of 250 microamperes. Indicator segments requiring up to 40 milliamperes of current may be driven directly from the SN5446A or SN5447A high-performance output transistors. Segment identification with resultant displays are shown in Figure A. Display patterns for BCD input counts above 9 are unique symbols to authenticate input conditions.

description (continued)

The SN5446A, SN5447A, and SN5448 circuits incorporate automatic leading and/or trailing edge zero blanking control (RBI and RBO). Lamp test (LT) of these types may be performed at any time when the BI/RBO node is a logical 1. All types contain an overriding blanking input (BI) which can be used to control the lamp intensity or to inhibit the outputs. All inputs except the BI/RBO nodes are one normalized Series 54/74 load. Inputs and outputs are entirely compatible for use with TTL or DTL logic outputs. Power dissipation is typically 320 milliwatts (SN5446A, SN5447A, and SN5448) or 165 milliwatts (SN5449).

The SN5446A, SN5447A, SN5448 and SN5449 are characterized for operation over the full military temperature range of −55°C to 125°C. The SN7446A, SN7447A, SN7448, and SN7449 (electrically identical to the corresponding Series 54 types) are for operation over the temperature range of 0°C to 70°C.

α

TRUTH TABLE SN5446A, SN5447A, SN7446A, SN7447A

	INPUTS							OUTPUTS							
DECIMAL OR FUNCTION	LT	RBI	D	C	B	A	BI/RBO	a	b	c	d	e	f	g	NOTE
0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1
1	1	X	0	0	0	1	1	1	0	0	1	1	1	1	1
2	1	X	0	0	1	0	1	0	0	1	0	0	1	0	
3	1	X	0	0	1	1	1	0	0	0	0	1	1	0	
4	1	X	0	1	0	0	1	1	0	0	1	1	0	0	
5	1	X	0	1	0	1	1	0	1	0	0	1	0	0	
6	1	X	0	1	1	0	1	1	1	0	0	0	0	0	
7	1	X	0	1	1	1	1	0	0	0	1	1	1	1	
8	1	X	1	0	0	0	1	0	0	0	0	0	0	0	
9	1	X	1	0	0	1	1	0	0	0	1	1	0	0	
10	1	X	1	0	1	0	1	1	1	1	0	0	1	0	
11	1	X	1	0	1	1	1	1	1	0	0	1	1	0	
12	1	X	1	1	0	0	1	1	0	1	1	1	0	0	
13	1	X	1	1	0	1	1	0	1	1	0	1	0	0	
14	1	X	1	1	1	0	1	1	1	1	0	0	0	0	
15	1	X	1	1	1	1	1	1	1	1	1	1	1	1	
BI	X	X	X	X	X	X	0	1	1	1	1	1	1	1	2
RBI	1	0	0	0	0	0	0	1	1	1	1	1	1	1	3
LT	0	X	X	X	X	X	1	0	0	0	0	0	0	0	4

NOTES: 1. BI/RBO is wire AND logic serving as blanking input (BI) and/or ripple blanking output (RBO). The blanking input (BI) must be open or held at a logical 1 when output functions 0 through 15 are desired, and the ripple blanking input (RBI) must be open or at a logical 1 if blanking of a decimal 0 is not desired. X = input may be high or low.
2. When a logical 0 is applied directly to the blanking input (forced condition) all segment outputs go to a logical 0 regardless of the state of any other input condition.
3. When the ripple blanking input (RBI) and inputs A, B, C, and D are at logical 0, with the lamp test input at logical 1, all segment outputs go to a logical 1 and the ripple blanking output (RBO) goes to a logical 0 (response condition).
4. When the blanking input/ripple blanking output (BI/RBO) is open or held at a logical 1, and a logical 0 is applied to the lamp test input, all segment outputs go to a logical 0.

TRUTH TABLE SN5448, SN7448

	INPUTS							OUTPUTS							
DECIMAL OR FUNCTION	LT	RBI	D	C	B	A	BI/RBO	a	b	c	d	e	f	g	NOTE
0	1	1	0	0	0	0	1	1	1	1	1	1	1	0	
1	1	X	0	0	0	1	1	0	1	1	0	0	0	0	1
2	1	X	0	0	1	0	1	1	1	0	1	1	0	1	
3	1	X	0	0	1	1	1	1	1	1	1	0	0	1	
4	1	X	0	1	0	0	1	0	1	1	0	0	1	1	
5	1	X	0	1	0	1	1	1	0	1	1	0	1	1	
6	1	X	0	1	1	0	1	0	0	1	1	1	1	1	
7	1	X	0	1	1	1	1	1	1	1	0	0	0	0	
8	1	X	1	0	0	0	1	1	1	1	1	1	1	1	
9	1	X	1	0	0	1	1	1	1	1	0	0	1	1	
10	1	X	1	0	1	0	1	0	0	0	1	1	0	1	
11	1	X	1	0	1	1	1	0	0	1	1	0	0	1	
12	1	X	1	1	0	0	1	0	1	0	0	0	1	1	
13	1	X	1	1	0	1	1	1	0	0	1	0	1	1	
14	1	X	1	1	1	0	1	0	0	0	1	1	1	1	
15	1	X	1	1	1	1	1	0	0	0	0	0	0	0	
BI	X	X	X	X	X	X	0	0	0	0	0	0	0	0	2
RBI	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
LT	0	X	X	X	X	X	1	1	1	1	1	1	1	1	4

NOTES: 1. BI/RBO is wire AND logic serving as blanking input (BI) and/or ripple blanking output (RBO). The blanking input (BI) must be open or held at a logical 1 when output functions 0 through 15 are desired, and the ripple blanking input (RBI) must be open or at a logical 1 if blanking of a decimal 0 is not desired. X = input may be high or low.
2. When a logical 0 is applied directly to the blanking input (forced condition) all segment outputs go to a logical 0 regardless of the state of any other input condition.
3. When the ripple blanking input (RBI) and inputs A, B, C, and D are at logical 0, with the lamp test at logical 1, all segment outputs go to a logical 0 and the ripple blanking output (RBO) goes to a logical 0 (response condition).
4. When the blanking input/ripple blanking output (BI/RBO) is open or held at a logical 1, and a logical 0 is applied to the lamp test input, all segment outputs go to a logical 1.

TRUTH TABLE SN5449, SN7449

	INPUTS					OUTPUTS							
DECIMAL OR FUNCTION	D	C	B	A	BI	a	b	c	d	e	f	g	NOTE
0	0	0	0	0	1	1	1	1	1	1	1	0	1
1	0	0	0	1	1	0	1	1	0	0	0	0	
2	0	0	1	0	1	1	1	0	1	1	0	1	
3	0	0	1	1	1	1	1	1	1	0	0	1	
4	0	1	0	0	1	0	1	1	0	0	1	1	
5	0	1	0	1	1	1	0	1	1	0	1	1	
6	0	1	1	0	1	0	0	1	1	1	1	1	
7	0	1	1	1	1	1	1	1	0	0	0	0	
8	1	0	0	0	1	1	1	1	1	1	1	1	
9	1	0	0	1	1	1	1	1	0	0	1	1	
10	1	0	1	0	1	0	0	0	1	1	0	1	
11	1	0	1	1	1	0	0	1	1	0	0	1	
12	1	1	0	0	1	0	1	0	0	0	1	1	
13	1	1	0	1	1	1	0	0	1	0	1	1	
14	1	1	1	0	1	0	0	0	1	1	1	1	
15	1	1	1	1	1	0	0	0	0	0	0	0	
BI	X	X	X	X	0	0	0	0	0	0	0	0	2

NOTES: 1. The blanking input must be open or held at a logical 1 when output functions 0 through 15 are desired.
2. When a logical 0 is applied to the blanking input all segment [illegible]

MSI TTL HIGH-SPEED DECADE COUNTERS

for applications in

- Digital Computer Systems
- Data-Handling Systems
- Control Systems

gic

TRUTH TABLES

BCD COUNT SEQUENCE (See Note 1)

COUNT	OUTPUT D	OUTPUT C	OUTPUT B	OUTPUT A
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

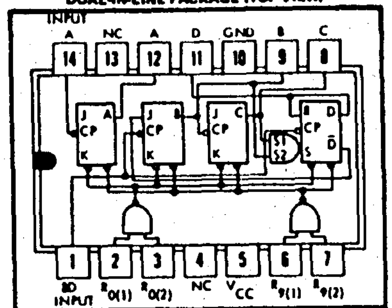
RESET/COUNT (See Note 2)

RESET INPUTS				OUTPUT
$R_{0(1)}$	$R_{0(2)}$	$R_{9(1)}$	$R_{9(2)}$	D C B A
1	1	0	X	0 0 0 0
1	1	X	0	0 0 0 0
X	X	1	1	1 0 0 1
X	0	X	0	COUNT
0	X	0	X	COUNT
0	X	X	0	COUNT
X	0	0	X	COUNT

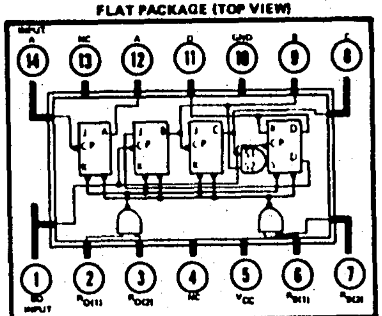
NC—No Internal Connection

NOTES: 1. Output A connected to input BD for BCD count.
2. X indicates that either a logical 1 or a logical 0 may be present.

J OR N
DUAL-IN-LINE PACKAGE (TOP VIEW)



W
FLAT PACKAGE (TOP VIEW)



positive logic: see truth table

escription and typical count configurations

These high-speed, monolithic decade counters consist of four dual-rank, master-slave flip-flops internally interconnected to provide a divide-by-two counter and a divide-by-five counter. Gated direct reset lines are provided to inhibit count inputs and return all outputs to zero or to a binary coded decimal (BCD) count of 9. As the output from flip-flop A is not internally connected to the succeeding stages, the count may be separated in three independent count modes:

1. When used as a binary coded decimal decade counter, the BD input must be externally connected to the A output. The A input receives the incoming count, and a count sequence is obtained in accordance with the BCD count sequence truth table shown above. In addition to a conventional zero reset, inputs are provided to reset a BCD count for nine's complement decimal applications.

2. If a symmetrical divide-by-ten count is desired for frequency synthesizers or other applications requiring division of a binary count by a power of ten, the D output must be externally connected to the A input. The input count is then applied at the BD input and a divide-by-ten square wave is obtained at output A.

3. For operation as a divide-by-two counter and a divide-by-five counter, no external interconnections are required. Flip-flop A is used as a binary element for the divide-by-two function. The BD input is used to obtain binary divide-by-five operation at the B, C, and D outputs. In this mode, the two counters operate independently, however, all four flip-flops are reset simultaneously.

These circuits are completely compatible with Series 54/74 TTL and DTL logic families. Average power dissipation is 160 mW.

CIRCUIT TYPES SN5490, SN7490
DECADE COUNTERS

absolute maximum ratings (over operating temperature range unless otherwise noted)

Supply Voltage V_{CC} (See Note 3)		7 V
Input Voltage, V_{in} (See Notes 3 and 4)		5.5 V
Operating Free-Air Temperature Range:	SN5490 Circuits	−55°C to 125°C
	SN7490 Circuits	0°C to 70°C
Storage Temperature Range		−65°C to 150°C

NOTES: 3. These voltage values are with respect to network ground terminal.
4. Input signals must be zero or positive with respect to network ground terminal.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply Voltage V_{CC} (See Note 3): SN5490 Circuits	4.5	5	5.5	V
SN7490 Circuits	4.75	5	5.25	V
Normalized Fan-Out From Each Output (See Note 5)			10	
Width of Input Count Pulse, $t_{p(in)}$	50			ns
Width of Reset Pulse, $t_{p(reset)}$	50			ns

NOTE 5. Fan-out from output A to input BD and to 10 additional Series 54/74 loads is permitted.

electrical characteristics over recommended operating temperature range (unless otherwise noted)

PARAMETER		TEST FIGURE	TEST CONDITIONS†		MIN	TYP‡	MAX	UNIT
$V_{in(1)}$	Input voltage required to ensure logical 1 at any input terminal	1			2			V
$V_{in(0)}$	Input voltage required to ensure logical 0 at any input terminal	2					0.8	V
$V_{out(1)}$	Logical 1 output voltage	2	V_{CC} = MIN, I_{load} = −400 μA		2.4			V
$V_{out(0)}$	Logical 0 output voltage	1	V_{CC} = MIN, I_{sink} = 16 mA				0.4	V
$I_{in(1)}$	Logical 1 level input current at $R_{0(1)}$, $R_{0(2)}$, $R_{9(1)}$, or $R_{9(2)}$	3	V_{CC} = MAX, V_{in} = 2.4 V				40	μA
			V_{CC} = MAX, V_{in} = 5.5 V				1	mA
$I_{in(1)}$	Logical 1 level input current at input A	3	V_{CC} = MAX, V_{in} = 2.4 V				80	μA
			V_{CC} = MAX, V_{in} = 5.5 V				1	mA
$I_{in(1)}$	Logical 1 level input current at input BD	3	V_{CC} = MAX, V_{in} = 2.4 V				160	μA
			V_{CC} = MAX, V_{in} = 5.5 V				1	mA
$I_{in(0)}$	Logical 0 level input current at $R_{0(1)}$, $R_{0(2)}$, $R_{9(1)}$, or $R_{9(2)}$	4	V_{CC} = MAX, V_{in} = 0.4 V				−1.6	mA
$I_{in(0)}$	Logical 0 level input current at input A	4	V_{CC} = MAX, V_{in} = 0.4 V				−3.2	mA
$I_{in(0)}$	Logical 0 level input current at input BD	4	V_{CC} = MAX, V_{in} = 0.4 V				−6.4	mA
I_{OS}	Short-circuit output current§	5	V_{CC} = MAX	SN5490	−20		−57	mA
				SN7490	−18		−57	mA
I_{CC}	Supply current	3	V_{CC} = MAX	SN5490		32	46	mA
				SN7490		32	53	mA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions for the particular circuit type.

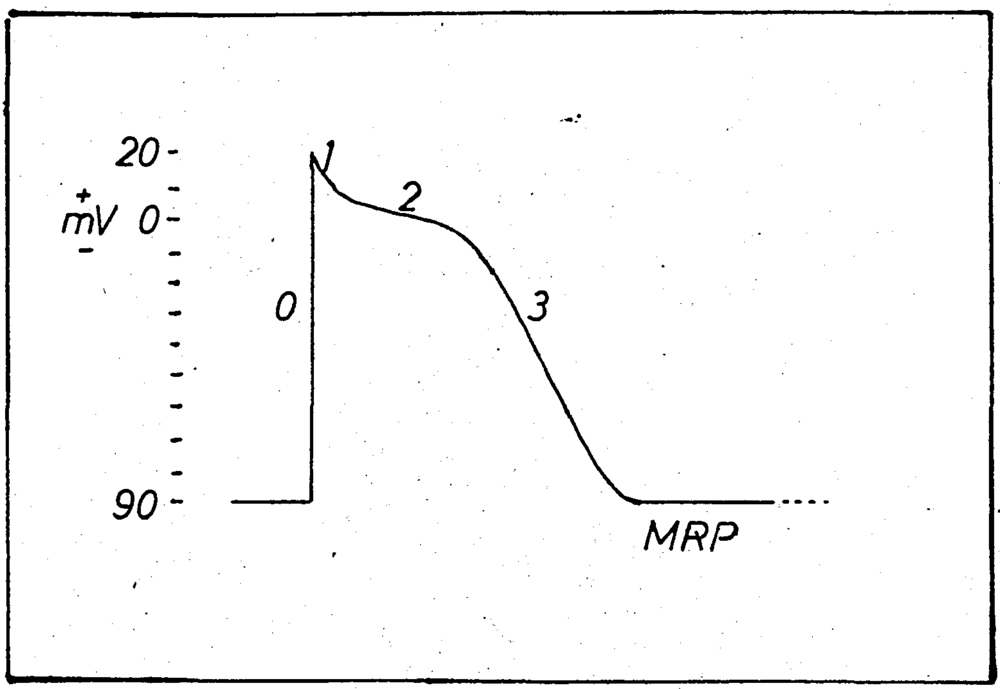


FIGURE 1. Diagram of the Action Potential of a Ventricular Muscle Cell

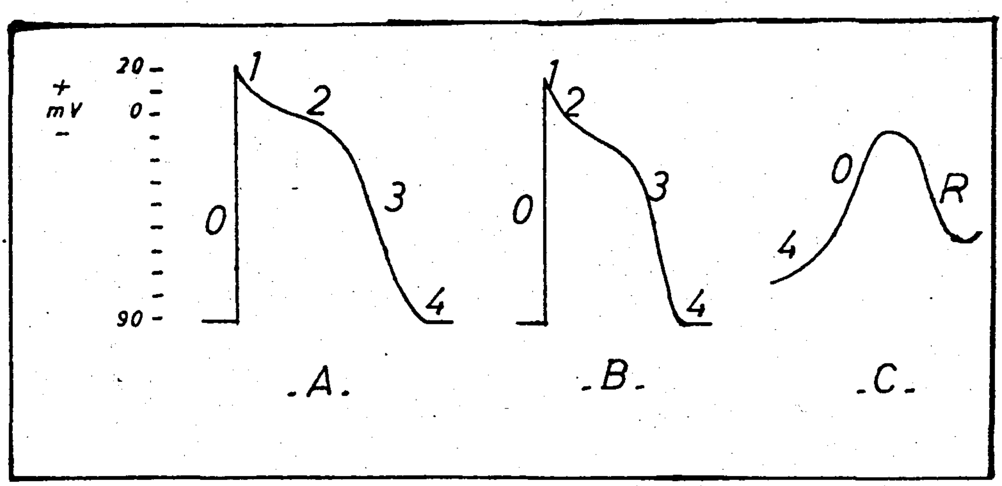


FIGURE 2. Diagram of Action Potential Curves

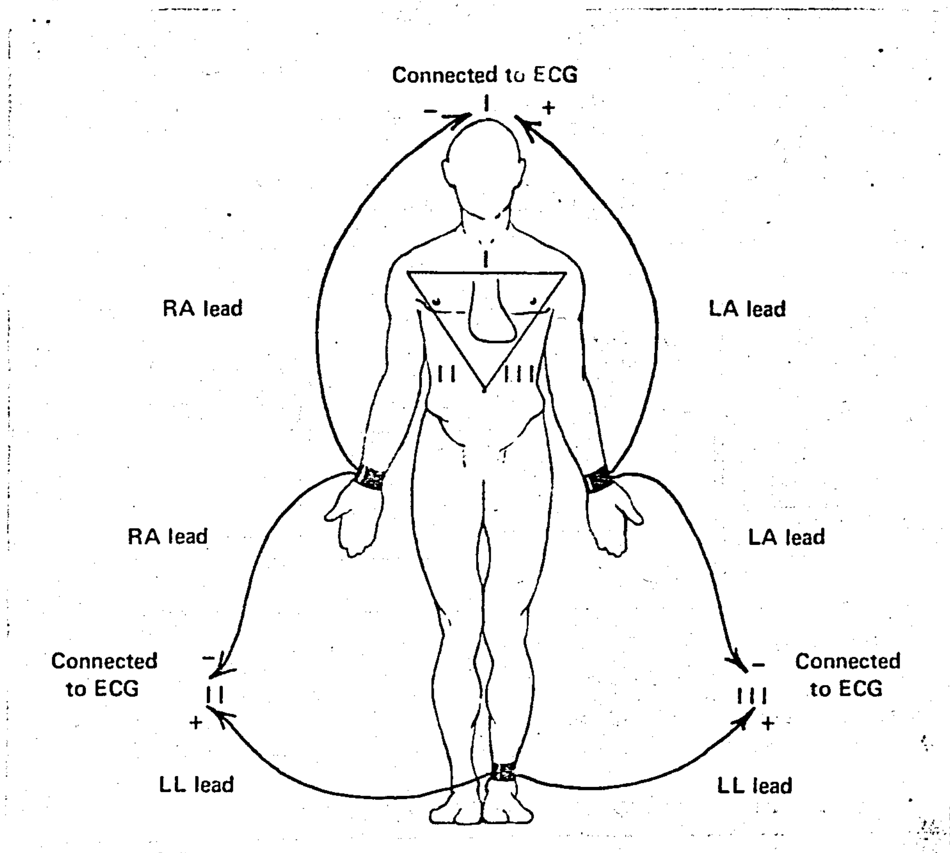


FIGURE 3. Connections for Bipolar Standard Leads I, II, and III.

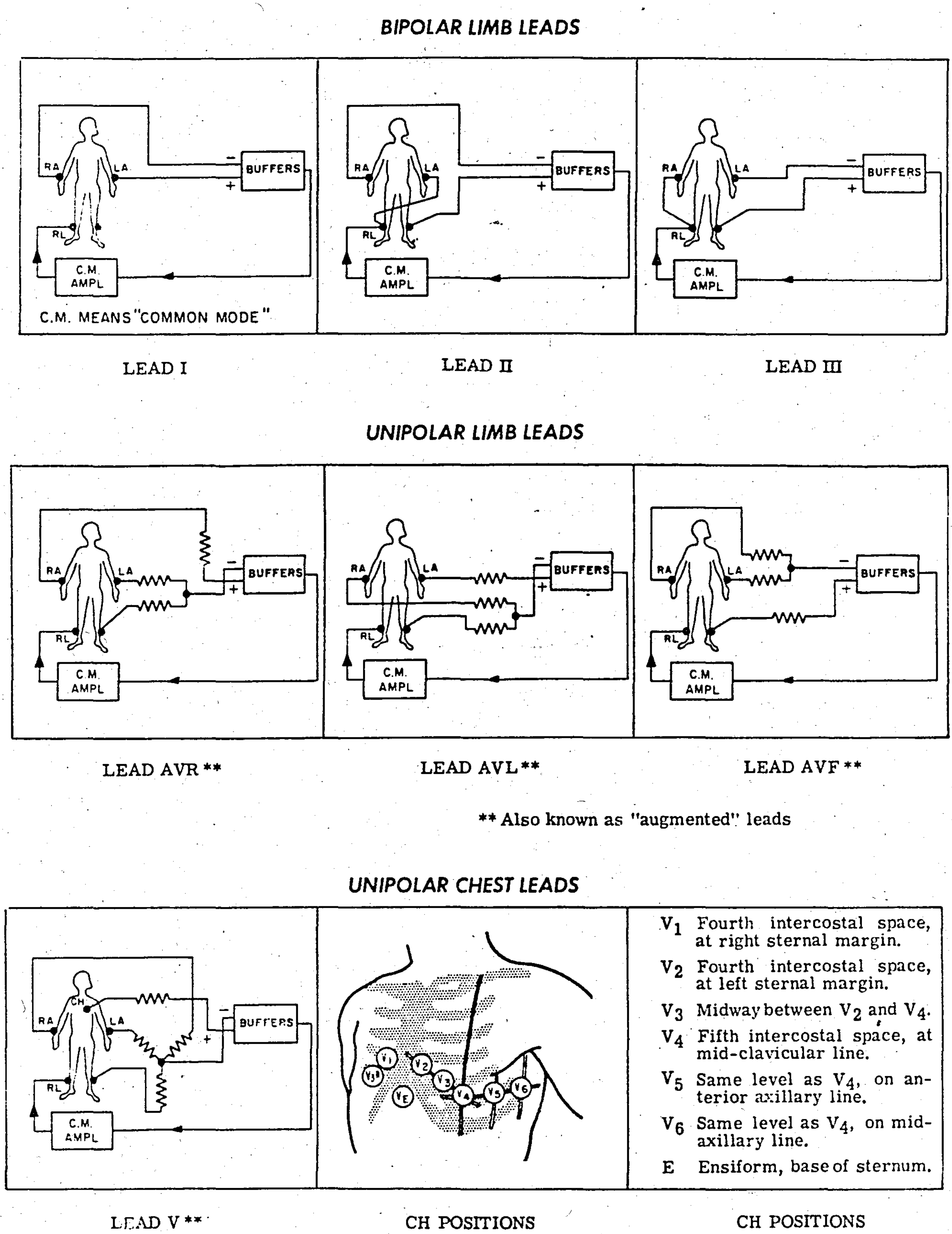


FIGURE 4. Standardized ECG Electrode Leads.

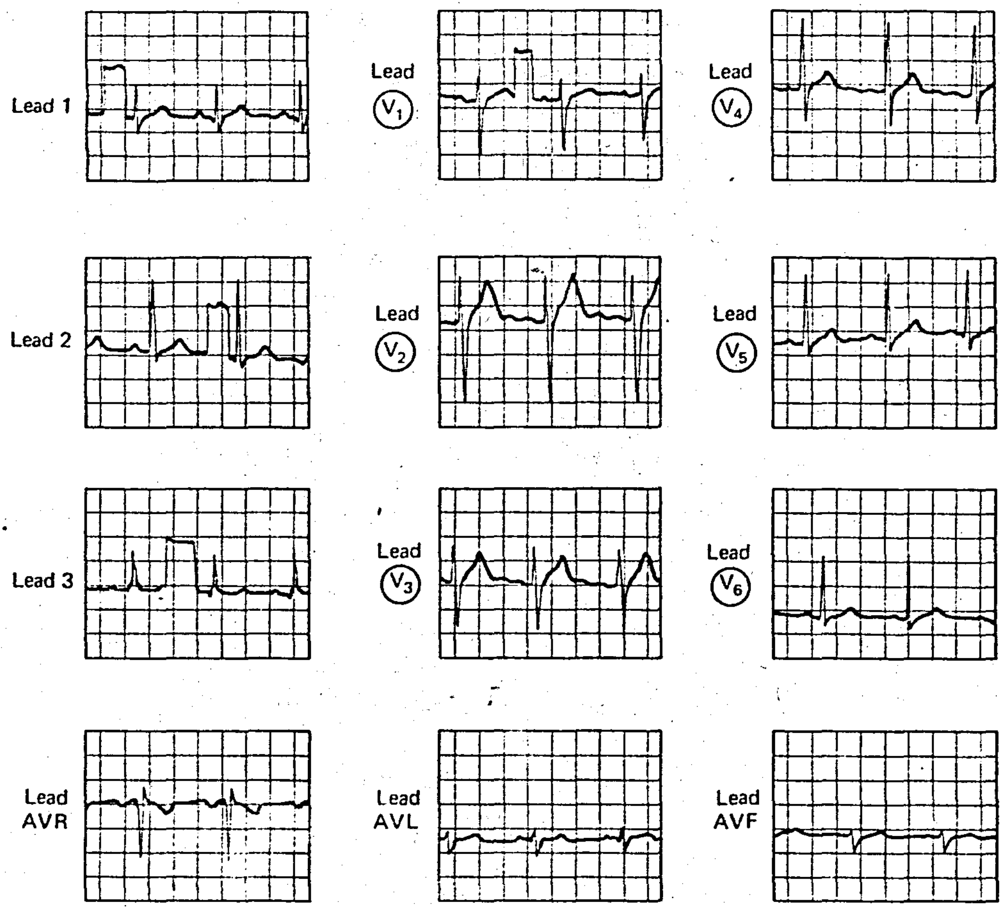


FIGURE 5. ECG Lead Waveform Variations

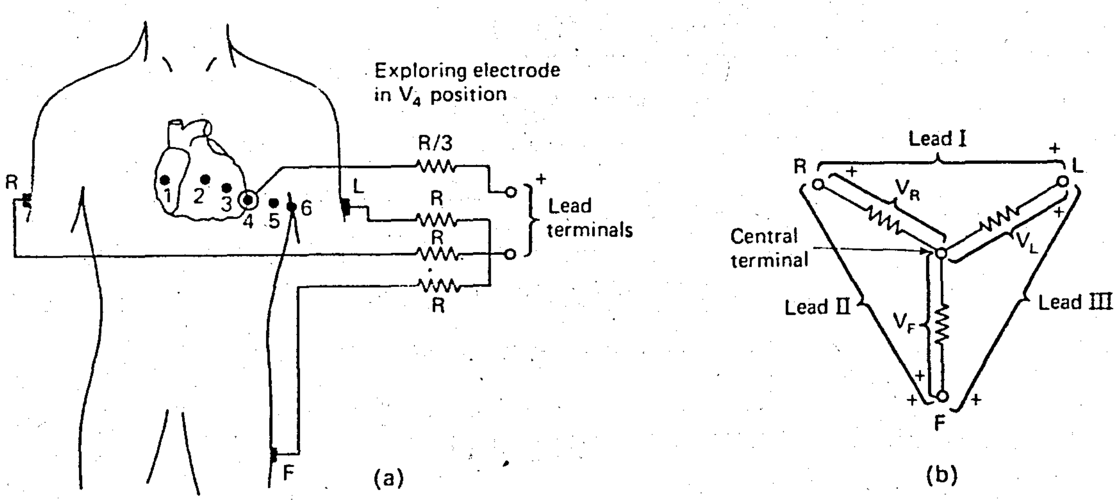


FIGURE 6. Wilson Electrode Network.

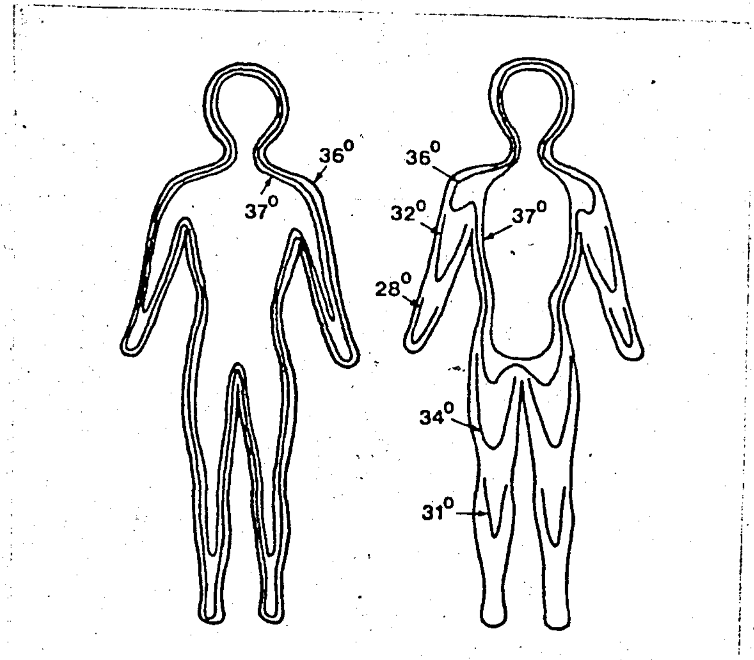


FIGURE 7. Isotherms (Surfaces Connecting Points of Equal Temperature) in the Body. Left, Isotherms in a Warm Environment; Right, in a Cold Environment.

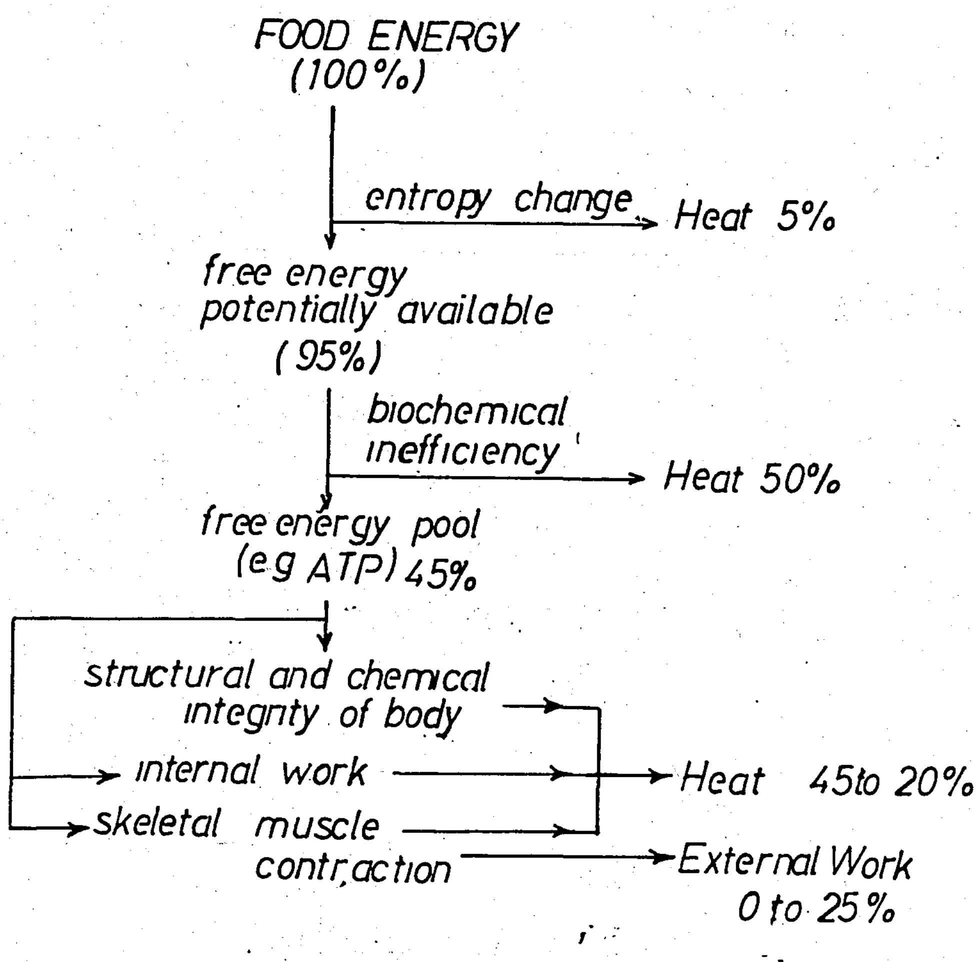


FIGURE 8. Summary of the Distribution of Ingested Food Energy Within the Body and Its Transfer to the Environment

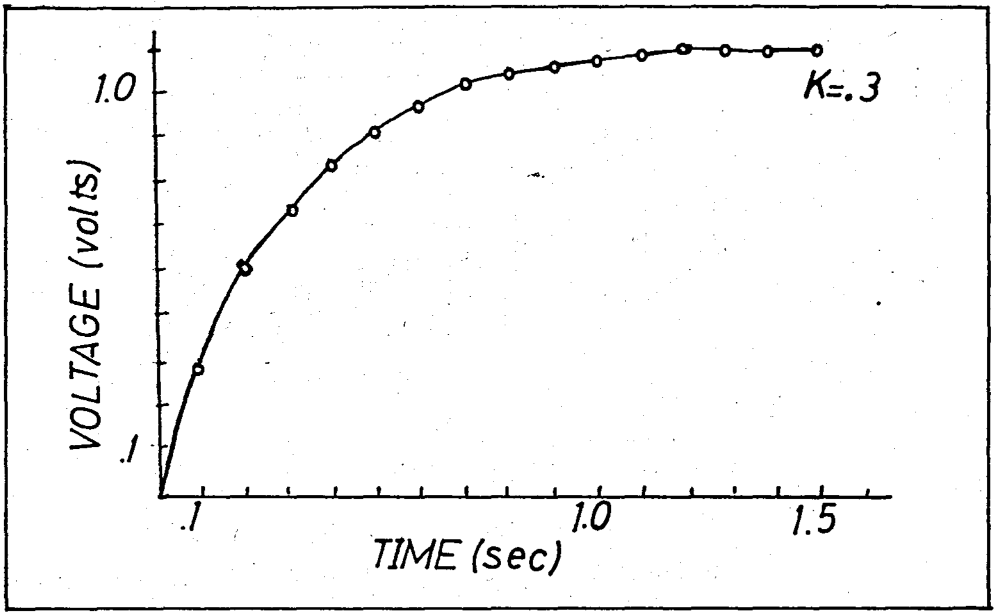


FIGURE 9. Capacitor Charging Curve as a Function of Period.

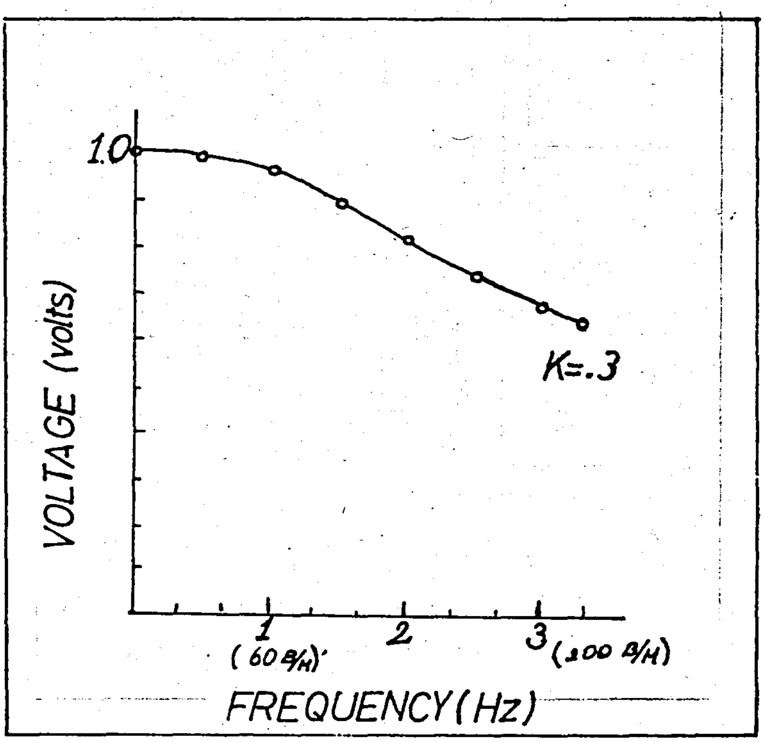
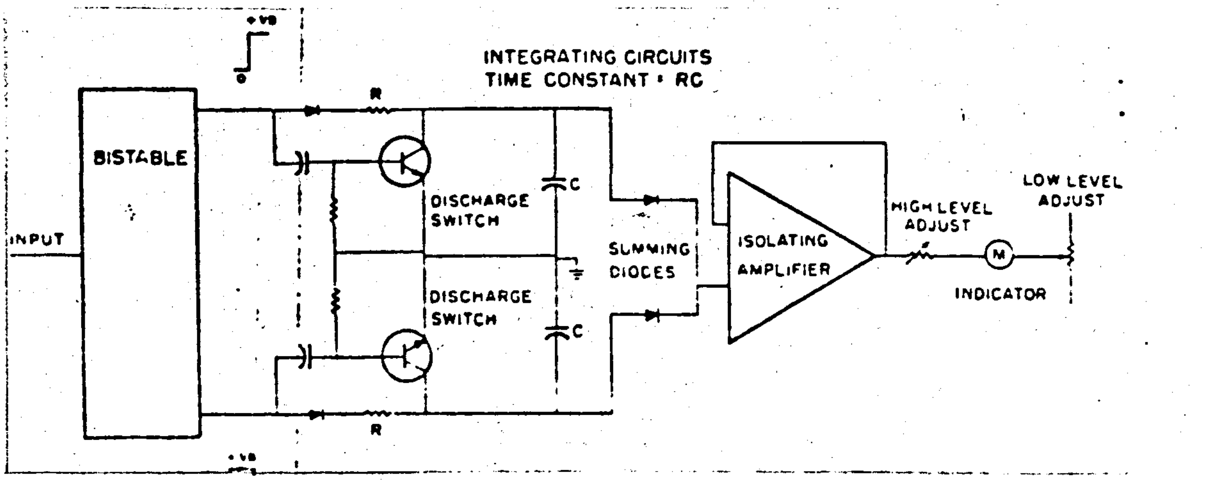
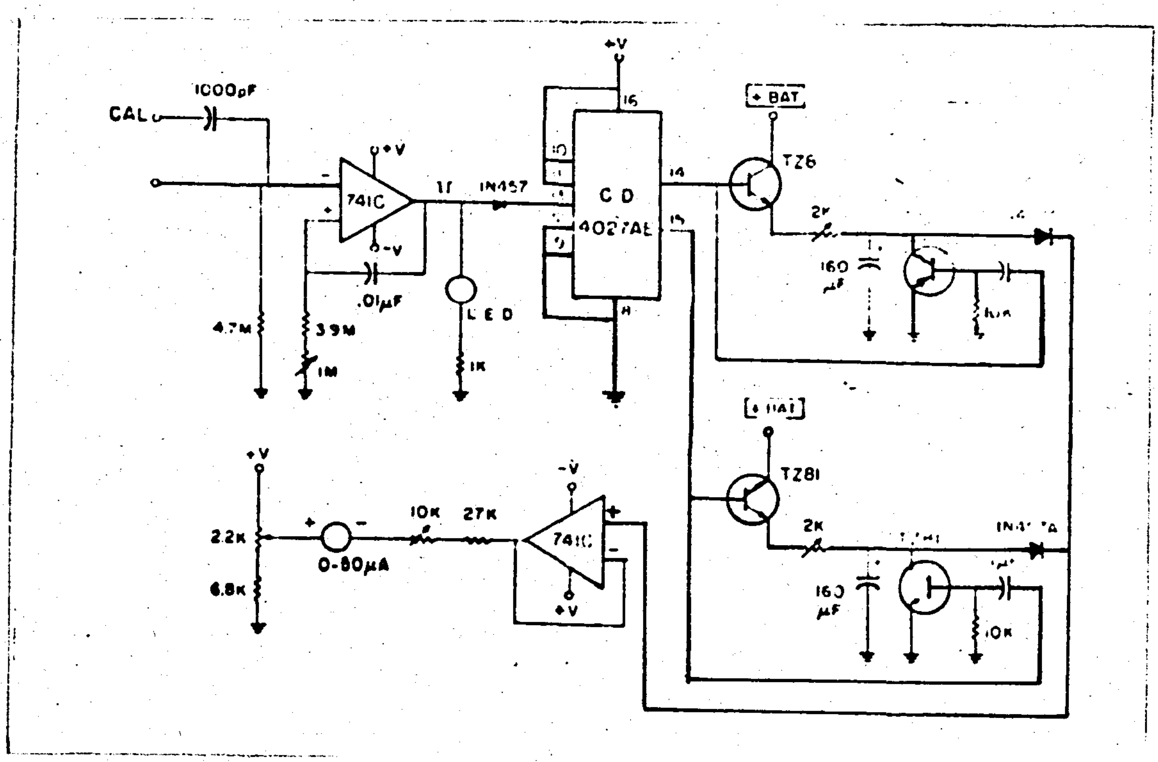


FIGURE 10. Capacitor Charging Curve as a Function of Frequency.



(a)

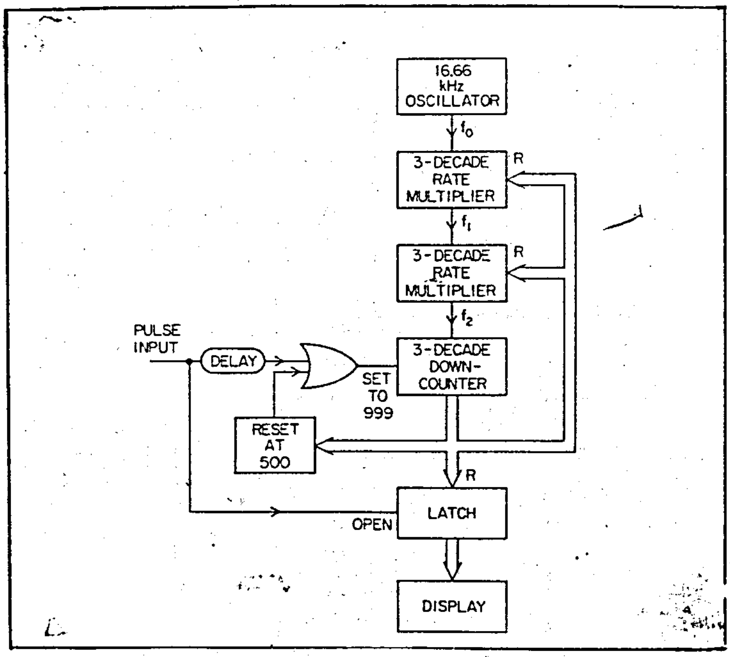
Circuit Diagram of Time Interval Counter



(b)

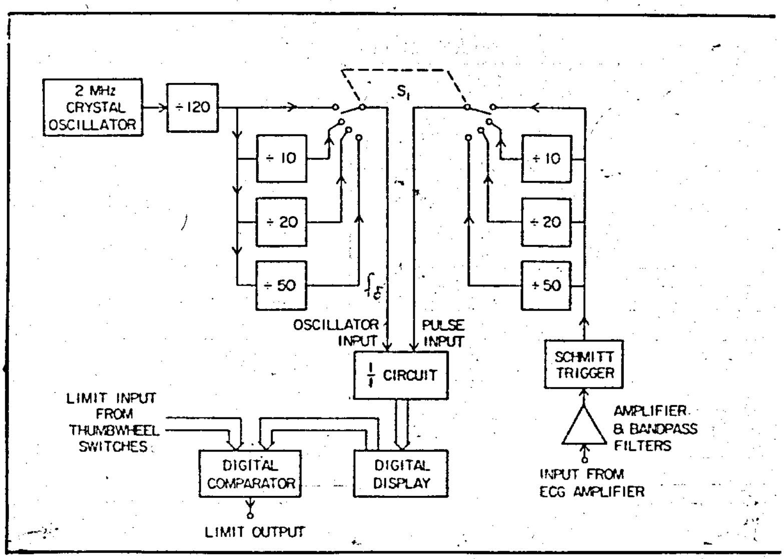
The Complete Circuit Diagram of the First Design

FIGURE 11



(a)

The Block Diagram of " $\frac{1}{t}$ clock"



(b)

The Block Diagram of the Second Design

FIGURE 12

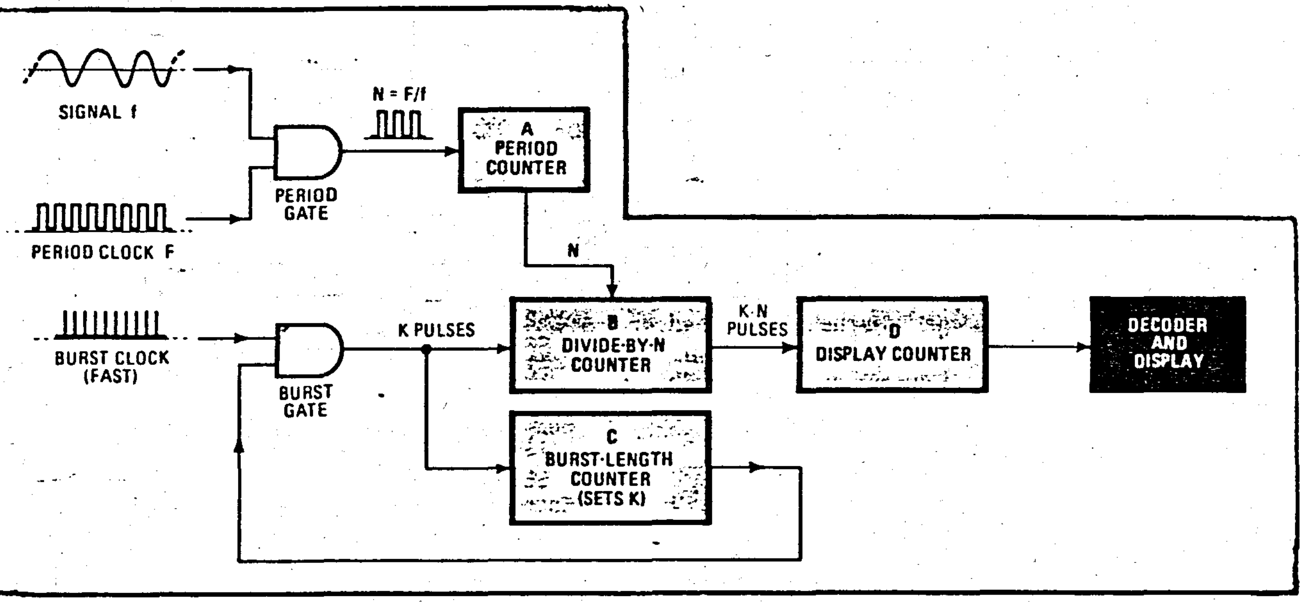


FIGURE 13. Block Diagram of the Third Cardiotachometer Design.

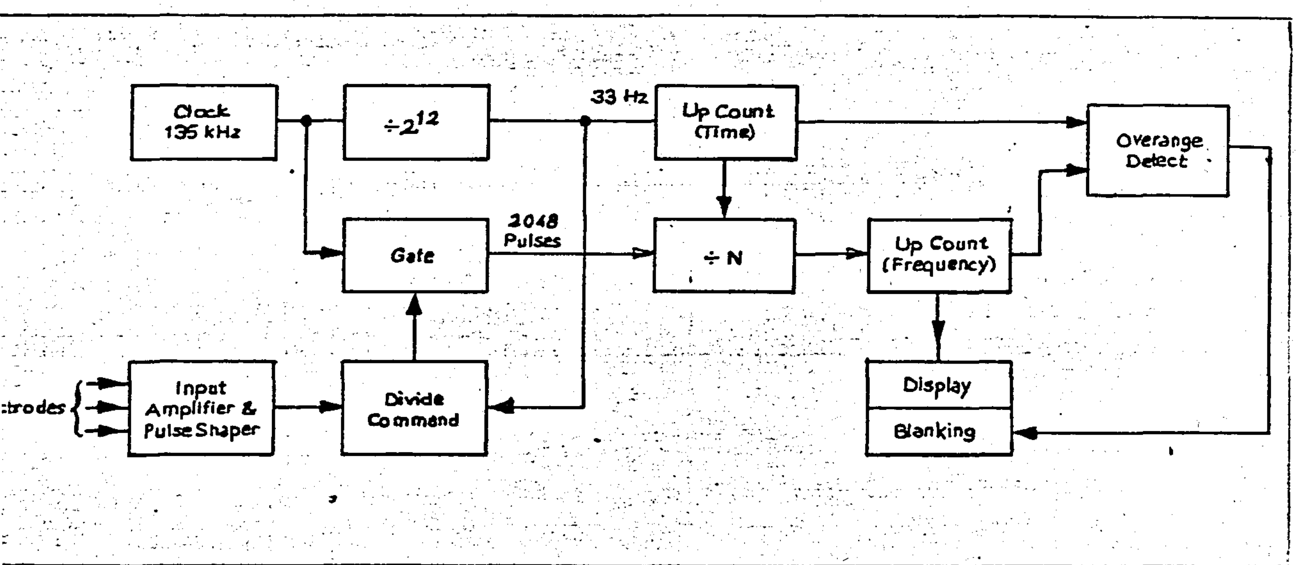


FIGURE 14. Block Diagram of the Fourth Cardiotachometer Design.

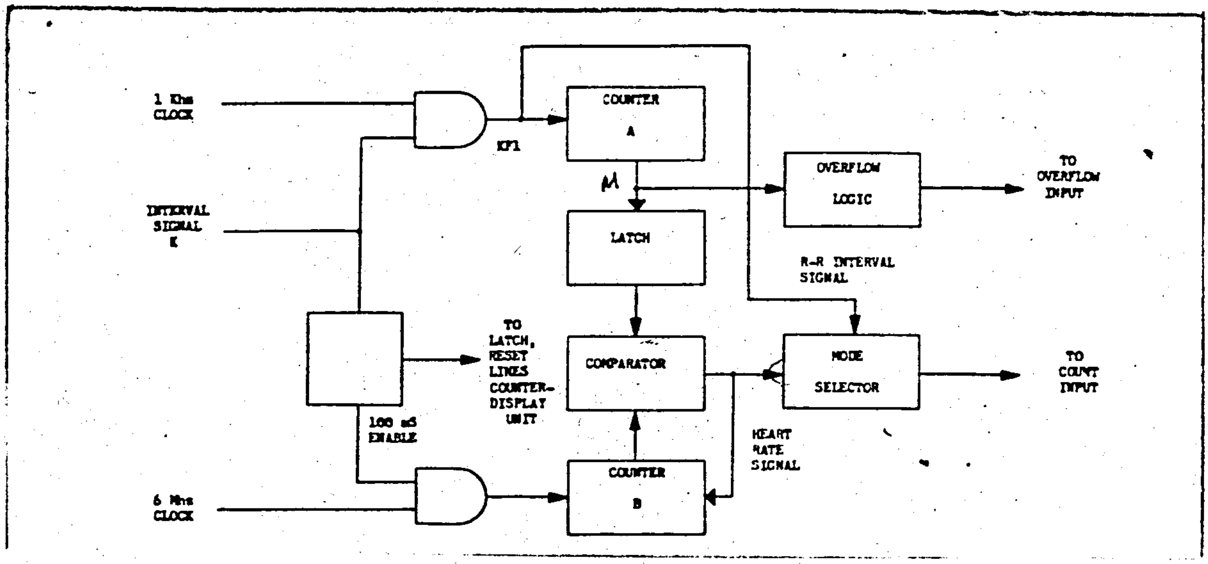


FIGURE 15. Block Diagram of the Fifth Cardiotachometer Design.

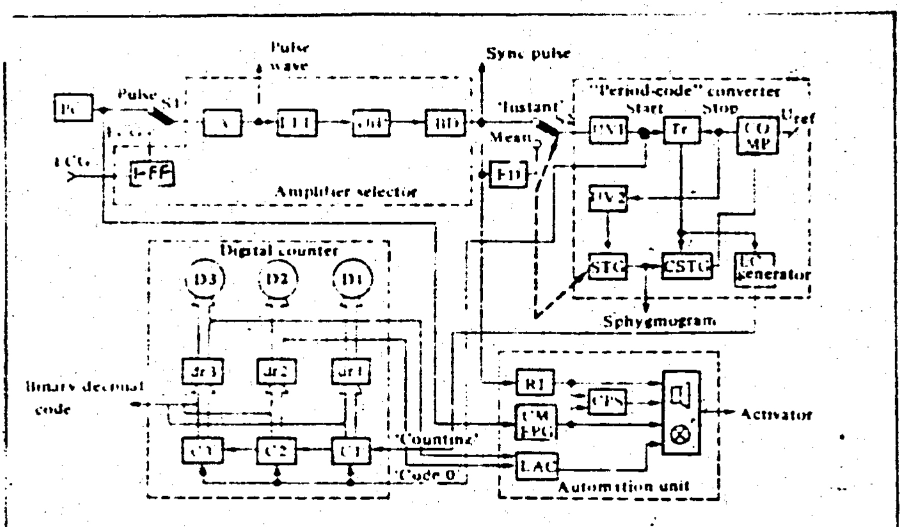


FIGURE 16. Block Diagram of the Sixth Cardiotachometer Design.

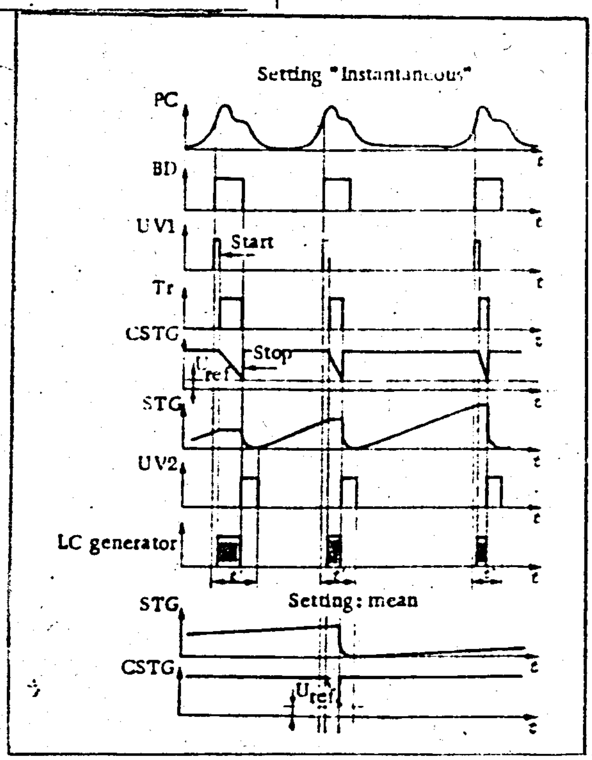


FIGURE 17. Provisional Diagram of the Operation of the Period-Code Converter.

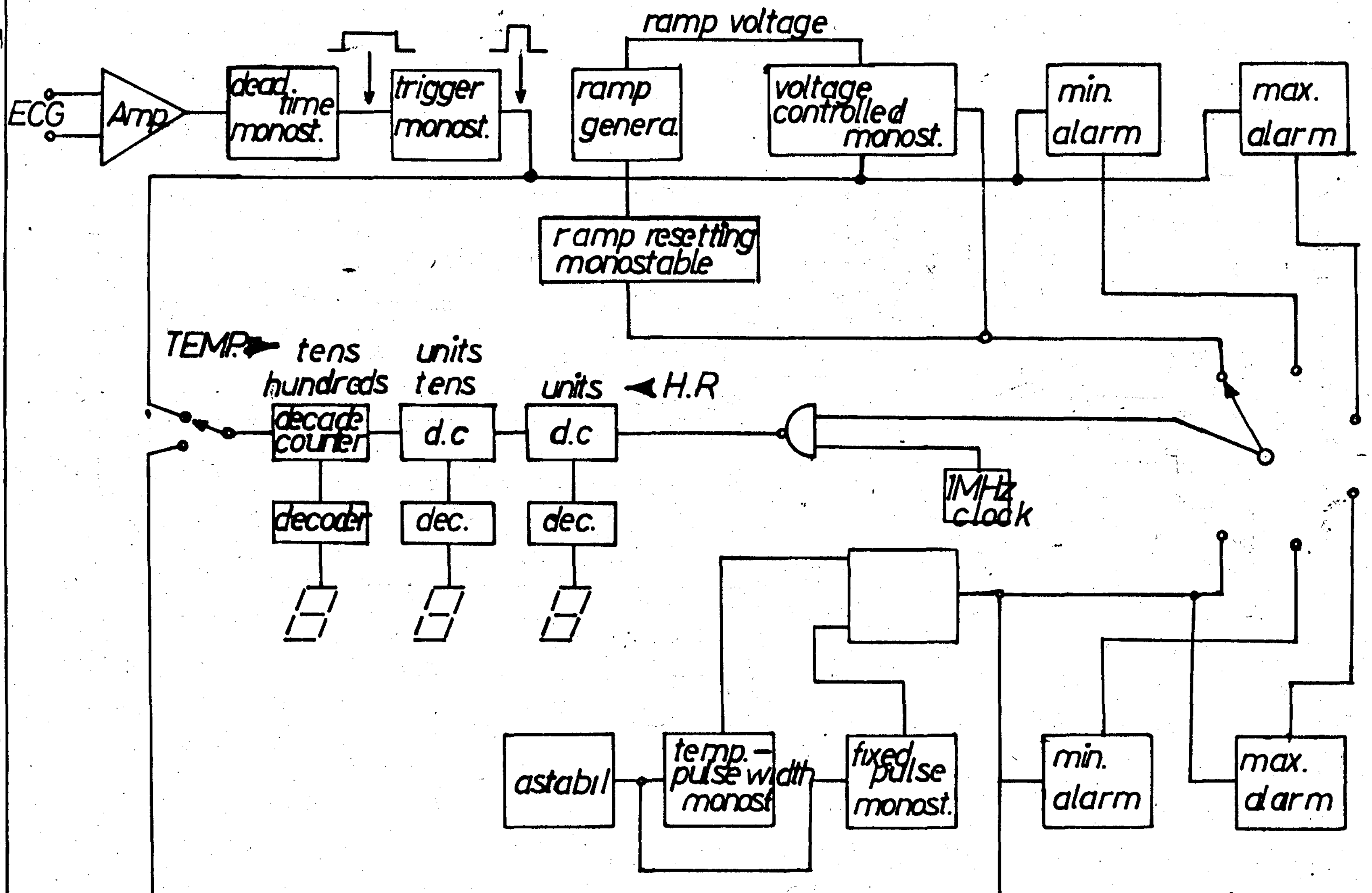


Fig. 19 BLOCK DIAGRAM

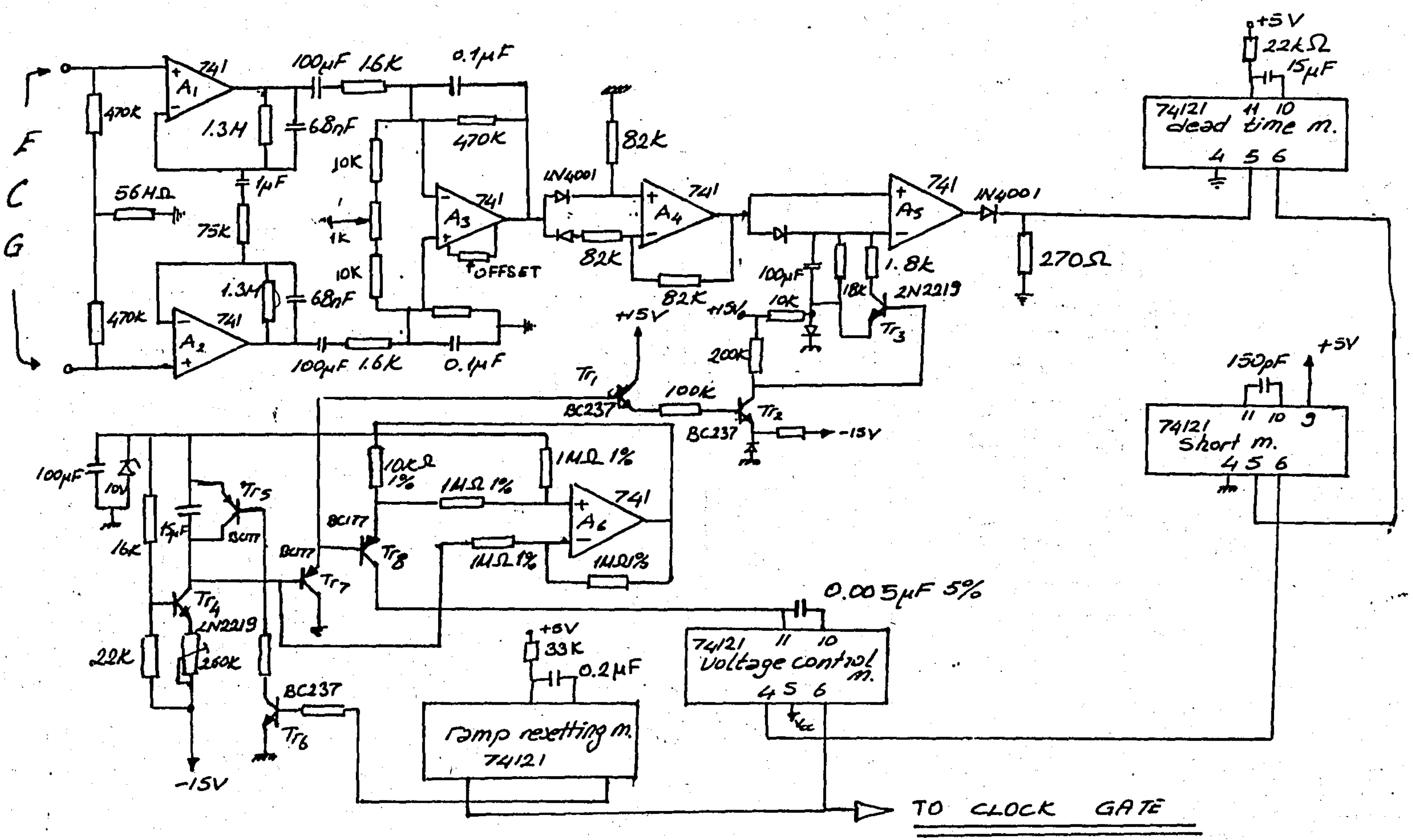
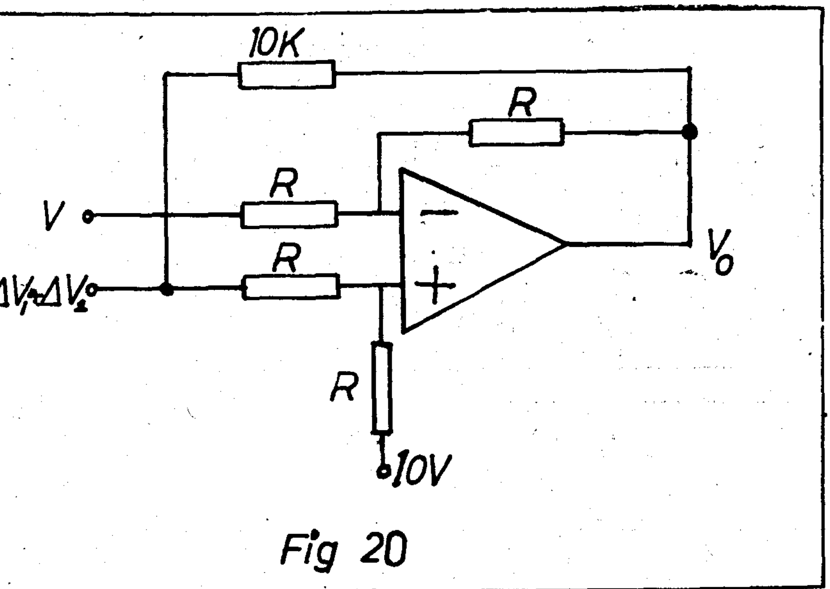
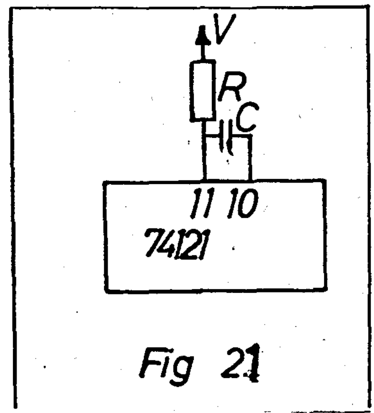


FIGURE 19. The Complete Diagram of Interval-to-Pulse Width Converter.





GURE 20. The Simplified Block Diagram of Voltage Difference to Current Converter.

The Connection of 74121

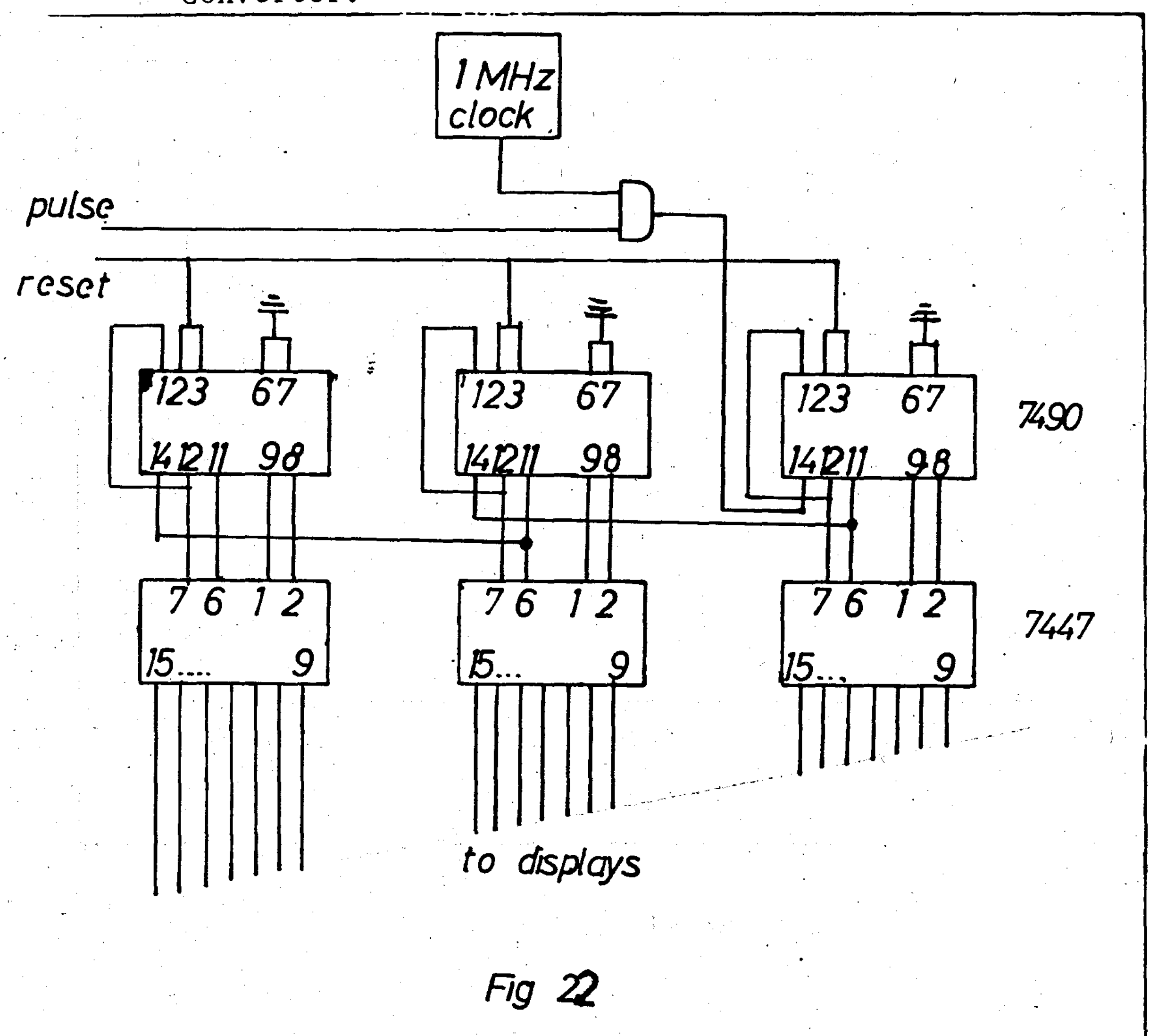


FIGURE 22. The Counter

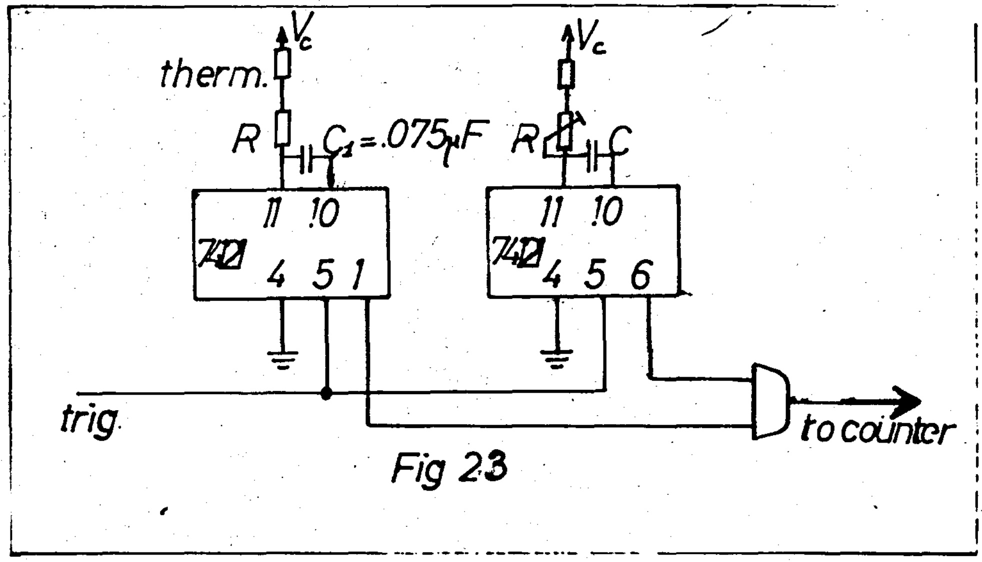


FIGURE 23. The Complete Circuit Diagram of Temperature-to-Pulse Width Converter

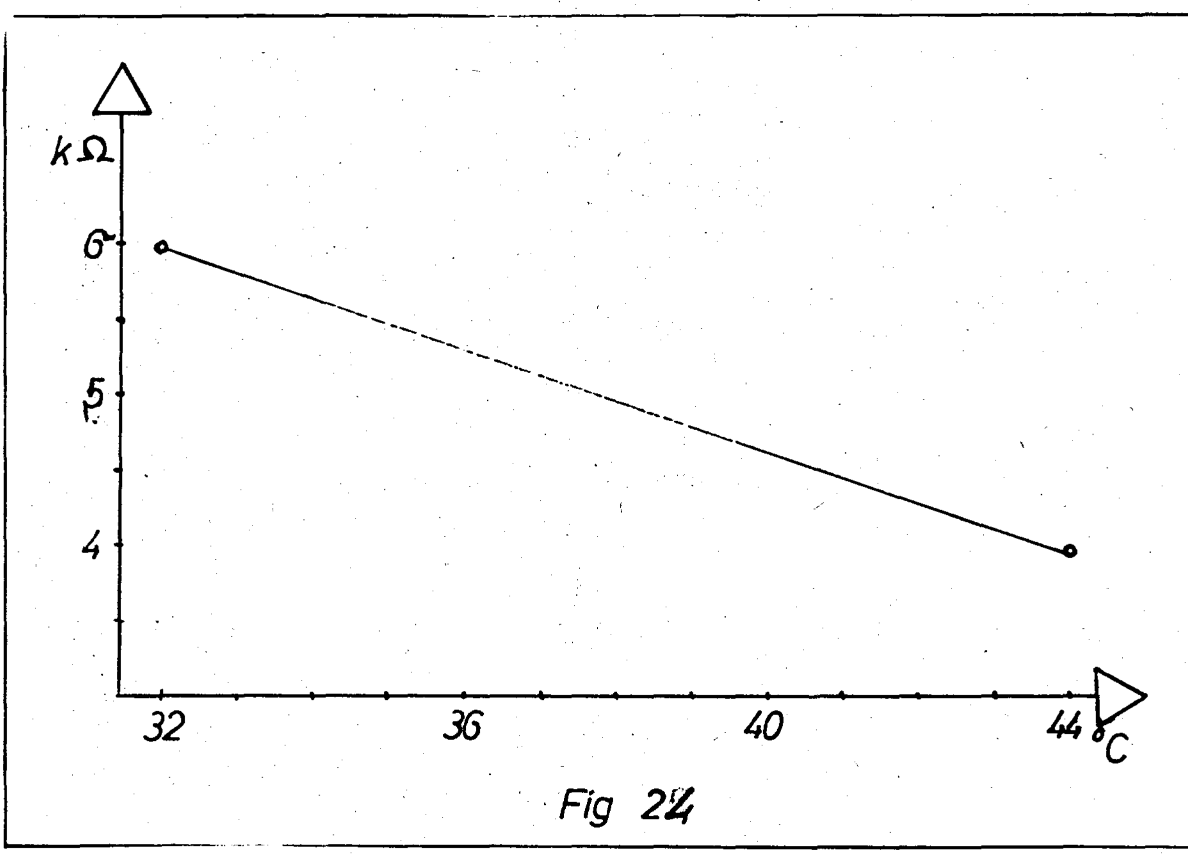


FIGURE 24. The Curve of Thermistor Resistance Versus Temperature.

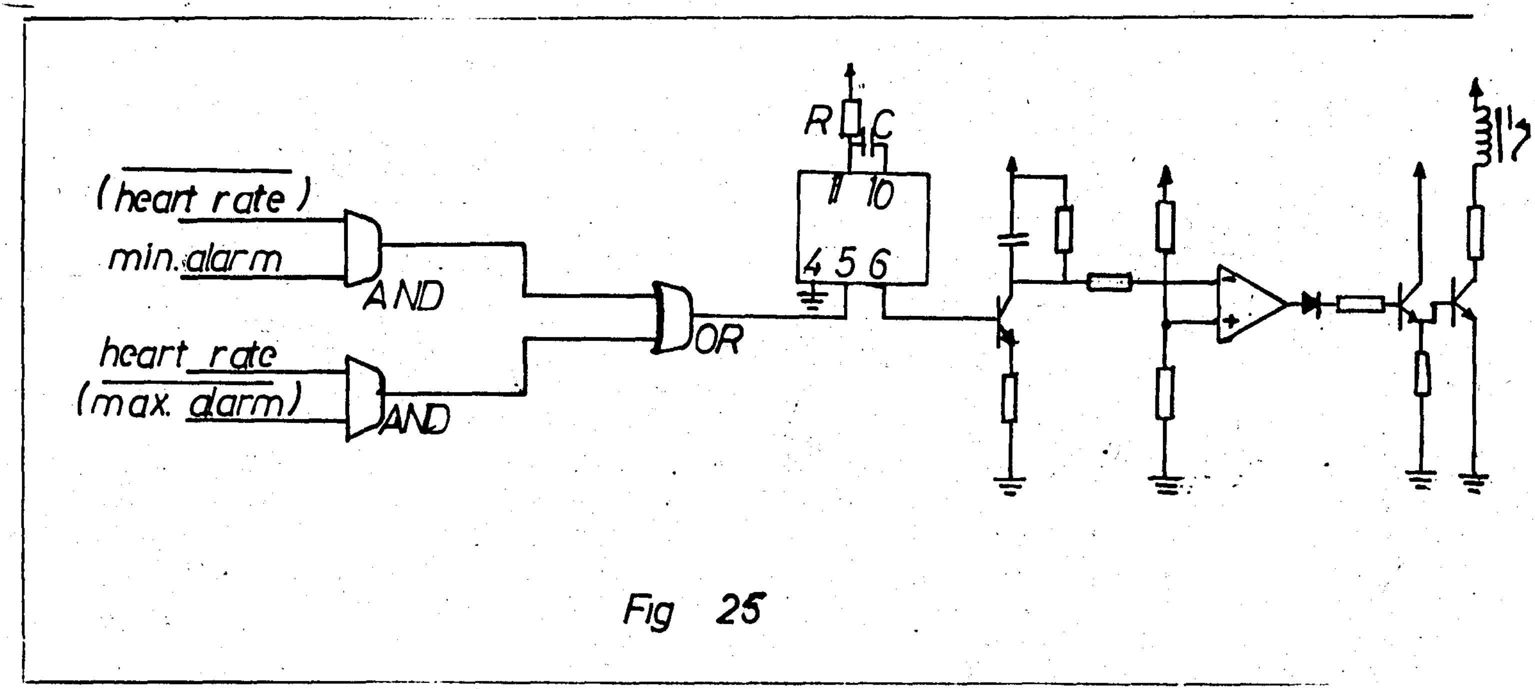


Fig 25

FIGURE 25. Alarm Circuit

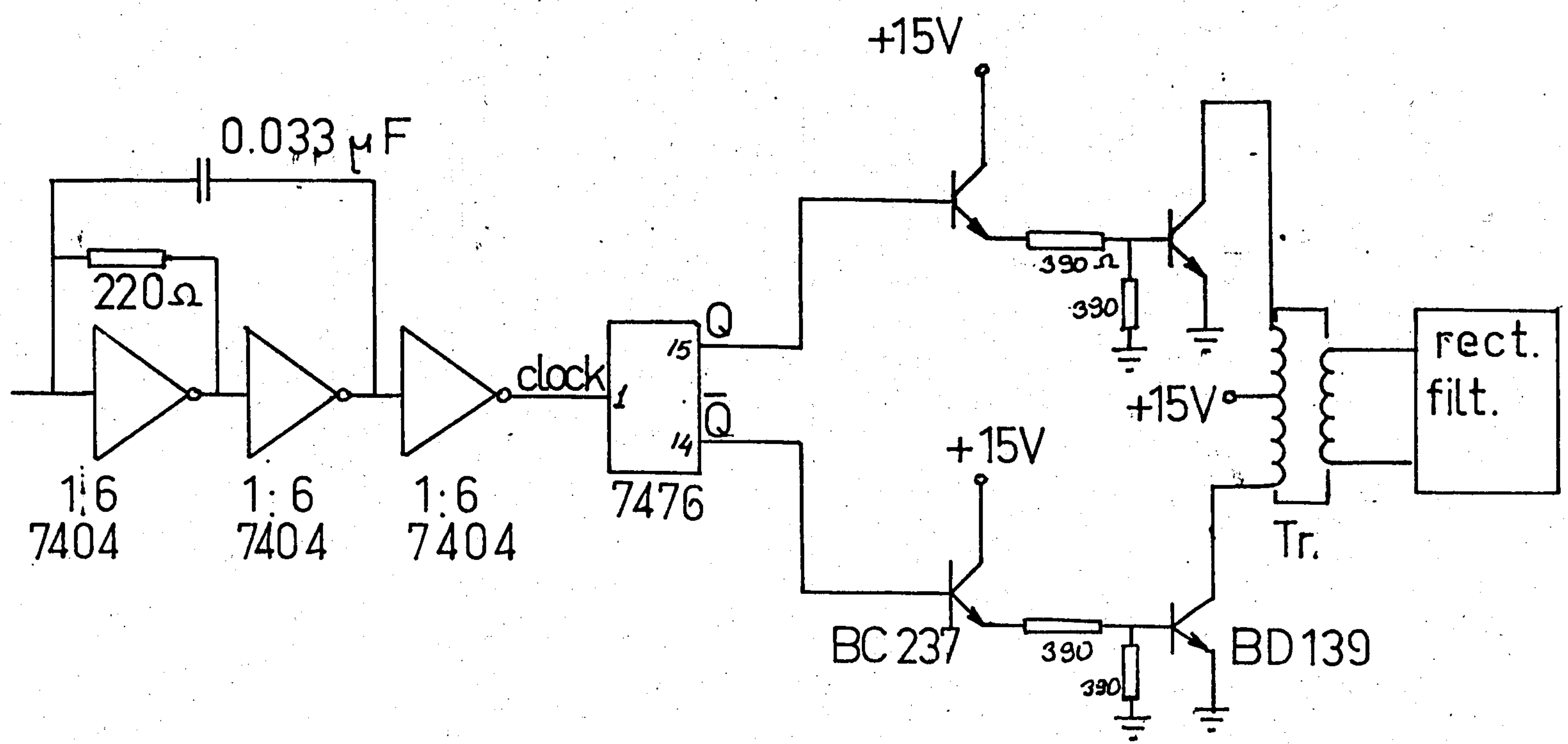


FIGURE 26. Isolated Power Supply

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