RESEARCH INSTITUTE
FOR PUBLIC HEALTH ENGINEERING T.N.O.

Report no 13

June 1952

U.D.C.: 612.172.2.-008.31
616.12.-008.31
621.317.761:612.172.2

A CARDIOTACHOMETER (PULSE RATE METER)

by

D.H. Bekkering and H.J. van Dal

The Hague (The Netherlands) Koningskade 12

PREFACE

A request emanating from medical circles as to whether it was possible to construct a simple device for continuous indication and registration of the pulse rate in subjects performing exercises brought us to the development of the pulse rate meter described in this report.

The instrument was developed at the Physical Laboratory of the National Defence Research Council T.N.O. at the Hague. The authors are glad of this opportunity to express their indebtedness to the Director of the Physical Laboratory for his kind hospitality and to his collaborators for their most valuable advice and help.

The development and the construction was carried out mainly by H.J. van Dal.

From January first of 1952 the medical-physical research work is transferred to the Medical-Physical Department of the National Health Research Council T.N.O. (Koningskade 12, the Hague). This Department can give any information concerning the subject, this report deals with.

CONTENTS

FIGURES:

SUMMARY

A pulse rate meter is described in which a milliammeter indicates the time intervals between all consecutive systoles of the heart. The scale is calibrated in beats per minute, ranging from 50 to 200.

Because of the action of the heart changes occur in the blood-content of the ear. These changes are transduced by means of a small electric bulb and a photocell into saw tooth shaped potential variations, being amplified in a three stage push pull amplifier. The amplified signal is changed into a square wave, so that the shape and the amplitude of the signal do not affect the meter reading. This square wave controls an electronic relay, which allows a condenser to be charged between every two systoles, making the voltage over this condenser a function of the time interval. This voltage is switched on to another condenser permanently connected to a vacuum tube voltmeter. Registration facilities are provided. A checking circuit is included. The apparatus is mains operated.

No error due to movements or muscular strains of the subject are encountered. One of the first requirements of physiological investigations in cardiac changes during exercise and emotion is thus fulfilled.

It is expected that the apparatus will render good services in other cases in which a continuous indication and recording of the pulse rate is wanted. As applications may be mentioned investigations on the field of

physiology: functional examination of the heart, exercise,
fatigue and training;
clinical examination: arhythmy
surgery: controlling the narcosis
pharmacotherapeutics: cardiaca, narcotica, sedativa
neurology and psychology.

A Dutch and an English version of this report was published.

RÉSUMÉ

Description d'un appareil pour la mesure de la fréquence du pouls, dans lequel un milliampèremètre indique la durée des intervalles de temps entre tous les deux systoles cardiaques consécutives. Gamme d'echelle 50 - 200 battements par minute.

Par suite de l'action du coeur ils se produisent des variations de remplissage sanguine de l'oreille, lesquelles sont transformées en variations de tension électrique en forme de dents de scie par une petite lampe et une cellule photo-électrique. Ces variations de tension sont amplifiées dans un amplificateur push-pull en trois étages. Le signal amplifié est transformé à une tension rectangulaire de telle façon que la forme et l'amplitude n'influencent pas l'indication du mètre. Cette tension rectangulaire règle un relais électronique, qui, entre deux systoles, charge un condensateur. La tension du condensateur est une fonction de l'intervalle de temps. Cette tension est transmise à un deuxième condensateur, couplé constamment à un voltmètre électronique. Enregistration est possible.

L'appareil est alimenté par courant alternatif, il comprend un vérificateur. Réglages complémentaires ne sont pas nécessaires.

Mouvements ou tensions des mucles du sujet d'expérience n'influencent pas l'indication du mètre. De cette manière une première demande aux expériences dans le domaine de la physiologie du travail est contentée.

On peut s'attendre à que l'appareil rendra de bonnes offices, notamment là où il est désirable de mesurer ou d'enregistrer continûment là fréquence du pouls. Comme applications on peut mentionner des recherches en domaine de la

physiologie: des recherches fonctionnels du coeur, du travail, de la fatigue et de l'entraînement; des observations cliniques arrhythmie
chirurgie: la contrôle de la narcose
pharmacotherapeutique: cardiaca, narcotica, sedativa
neurologie et psychologie.

Il y a paru de ce rapport une édition néerlandaise et une édition anglaise.

ZUSAMMENFASSUNG

Es wird ein Pulsfrequenzmesser beschrieben, welcher mittels ein Milliamperemeter die Länge der Zeitintervalle zwischen jede zwei aufeinanderfolgenden Systolen des Herzens anzeigt. Die Skala hat ein Bereich von 50 bis 200 Schlagen pro Minute.

Infolge der Wirkung des Herzens treten Änderungen in der Durchblutung des Ohrens auf, welche mittels ein Lämpchen und eine Photozelle in sägezahnförmige Spannungsänderungen umgewandelt werden. Diese Spannungsänderungen werden verstärkt in einem dreistufigen Gegentaktverstärker. Die verstärkte Signale werden in solcher Weise umgesetzt in rechteckigen Spannungen, dass die Form und die Grösse der Signalen keinen Einfluss haben auf die Messeranweisung und dann zugeführt an ein elektronisches Relais, welches einen Kondensator zwischen jeden zwei Systolen ladet. Die Spannung des Kondensators ist also eine Funktion des Zeitintervalles zwischen zwei aufeinanderfolgenden Systolen. Diese Spannung wird umgeschaltet auf einen zweiten Kondensator, dauern angeschlossen an einem Röhrenspannungsmesser. Eine Registrationsmöglichkeit ist vorgesehen. Der Apparat wird aus dem Netze gespeist. Ein Eichungskreis ist eingebaut, weiteres Einstellen ist nicht nötig.

Die Anweisung wird nicht zerstört durch Bewegungen oder Muskelspannungen der Versuchsperson. Dies ist eine erste Bedingung für Versuche auf dem Gebiete der Arbeitsphysiologie.

Es darf angenommen werden, dass der Apparat auch gute Diensten erweisen wird in Fällen wo die fortlaufenden Messung und Registrierung der Pulsfrequenz erwünscht ist.

Als Anwendungsgebiete können genennt werden Untersuchungen auf dem Gebiete der

Physiologie: funktionale Untersuchung des Herzens, Arbeit, Ermüdung
und Trainung;
klinische Untersuchungen: Arrhythmus
Chirurgie: Kontrolle der Narkose
Pharmakotherapie: Kardiaka, Narkotika, Sedativa
Neurologie und Psychologie.

Dieser Bericht is herausgegeben in niederländischer Sprache und in englischer Sprache.

1. INTRODUCTION

In many investigations and clinical cases it is desirable to know the pulse rate at a given moment, or the variations of the pulse rate during a given time. Usually this is done by feeling the pulse and counting the number of pulses during a certain time, whereafter the number of pulses per minute is to be calculated.

One thus obtains a mean value of the pulse rate during the time the pulses were counted. This method useful for the momentary determination of the pulse rate of a resting patient, will be troublesome with subjects performing excercises, especially when one is interested in the way the pulse rate varies during the experiment.

Aim of our research was the construction of an instrument making continuous feeling of the subject's pulse during physiological investigations superfluous.

As the present device was intended for an experiment in which the pulse rate was to be measured for about an hour, we did not claim to reproduce the exact difference in duration of two consecutive heartcycles. A modification of the system in which these differences are brought out better, is described and was realized as an intermediate result of our research.

2. LITERATURE REVIEW

The pulse is one of the oldest aids of the physician for making a diagnose. Until about 1800 the qualitative determination predominated, whereas little or no attention was paid to the quantitative determination of the heart rate.

In 1620 Galilei(1564-1642) (1) constructed the first pulse rate meter making use of the fact, that the period of vibration of a pendulum is proportional to the length of the pendulum. The length of the pendulum was shortened until the period of vibration corresponded with the pulse of the patient. The frequency could be read off a calibrated scale.

Early in the 18th century Sir John Floyer published a book "Physicians Pulse Watch" in which he made a thorough study of the pulse rate.

Kraus, Goldschmidt and Seelig (2) (3) constructed a pulse resonator based on the same principle Galilei used. The movement of the Arteria Radialis makes an electric contact by means of a lever. The excited current pulses flow through the coil of an electromagnet, surrounded by 24 pendula having different own frequencies. The pendulum ~~which~~ whose own frequency approximates to the pulse frequency will show the greatest displacement. When a pendulum becomes a certain predetermined displacement an electric contact is made and an electric current writes on especially prepared paper. This pulse resonator however did not give satisfactory results. The instrument only gives the mean value of 5 till 10 intervals, whereas it can give only 6 till 8 pulse variations per minute. The pulse resonator fails entirely at rapid and large variations.

A. Fleisch (4,5,6) replaced the lever system of the pulse resonator by a mercury column, pressing against the Arteria Radialis by means of a membrane. Afterwards he developed another system for measuring the pulse rate. During the interval to be recorded an electric motor draws a style upward past a drum blackened by a smoky flame. At the beginning of the next systole the coupling between motor and style is broken by an electric contact, a spring pulls the style down, whereafter it is drawn upward again by the motor. The length of the drawn line (plus a certain length) is equal to the duration of the interval. This time interval is reciprocally proportionate with the frequency.

A disadvantage of this apparatus is that the fore arm of the subject is to be fixed immovably in order to fit the pulse membrane.

Fürstenberg and Hoffstaedt (7) published a comparative examination of the pulse resonator and the electrocardiograph.

Goldscheider (8) examined the regularity of the pulse with the aid of the pulse resonator. The differences between two consecutive beats would be between 0.008 and 0.109 sec. with healthy subjects at rest. After muscle exercises these irregularities increase, viz. 0.035 till 0.317 sec. With Basedow's disease he found an extremely regular pulse (Pulsstarre). An artificial Pulsstarre can be obtained by narcosis and alcohol intoxication.

E.P. Boas (9) used the R-top of the electrocardiogram to actuate a relay, after being amplified in a four stage battery amplifier. The style of the relay draws a straight line on a paper film and deviates a few millimeters when the relay is actuated. The number of tips can be counted.

In 1935 Whitehorn, Kaufman and Thomas (10) published a report of a series of experiments, showing that the pulse rate varies very much at emotional disturbances.

In 1936 Schwarzschild and Shelesnyak (20) developed a pulse counter. The R-top of the electrocardiogram decreases the negative bias of a gas filled triode. The excited current pulses are counted by an electromagnetic counter. With the aid of a synchrone motor every minute a picture is made of the dialnumber after which a relay is actuated bringing the counter at its zero position again.

In 1937 Franklin Henry (11) described a pulse counter. Again the R top of the electrocardiogram was used to actuate a relay after sufficient amplification. A high amplification factor, viz. 10^6 could be obtained with a low noise level (4 μV.) by tuning the amplifier at 20 cycles per sec. The active electrode was placed on the chest, the other in the mouth. According to Henry the apparatus allows simple exercises of the subject. In our opinion muscle potentials in the thorax are bound to give false readings.

About one year later Henry (13) improved his counter. Instead of actuating a counting system the relay now connects a condenser alternately to a constant voltage source and to a discharging circuit. The time constant of this discharging circuit is such that the discharging frequency is filtered out making possible to determine the mean value of the voltage down to a frequency of 2 cycles per second. However it is not possible to increase this time constant for lower frequencies, because in that case in the higher frequency range integration arises. The voltage to be measured is impressed on a Wheatstone bridge, consisting of two thermionic valves and two resistances. The meter in the bridge is to be calibrated at the mean value of this voltage. On applying a constant low frequency the pointer will not remain at rest; but deflect till a given point at the scale and then move backward. This makes a accurate reading difficult.

In 1938 A. Djourno (12) described a simple mechanical pulse counter, in which the movement of the Arteria Radialis makes and breaks a relay circuit. This relay actuates a Strowger line finder switch as is used in automatic telephony.

M. Tiitso (14) has used the Fleisch pulse writer (4) at experiments on animals and compared with a blood pressure meter and an electrocardiograph.

Laurence, Morehouse and Tuttle (15), too, described a pulse counter in which the R top of the electrocardiogram is used to control a relay after being amplified adequatly. The electrodes are placed on the chest as close as possible to the heart. Good contact and low contact resistances are of great importance. The second stage of the amplifier is tuned at about 30 cycles per second. The attenuator is to be readjusted in each case to prevent false counting. The relay is to be actuated only by the R top. In case of too much amplification the T top, for instance, might cause an extra pulse thus giving a higher frequency reading. When the amplification is too low pulses might be missed (see fig. 7).

In 1941 Meyer and Seidel (17) composed a formula for the expression of the heart deficiency in secondevolume, pulse rate and venous pressure.

Dirk Albers (19) examined fifty subjects with heart vitia. The relation between the work done, the pulse rate and recovery time was examined for various heart vitia. Due to the small number of patients no important conclusion could be drawn. The author suggested to compare these results with the electrocardiogram, the oxygen uptake and carbondioxyde production.

E.A. Müller (18) searched the relation between pulse rate and training. The increase of achievement after training is due to improved exchange of blood in the muscle tissues. There is hardly any question of training of the heart, since after training of certain muscles this improvement does not hold for other muscles.

K. Matthes (16) described a reflexion meter. A hole is made in the centre of a selenium photocell and a light source is placed behind the cell. The light beam is reflected by the surface to be examined and the variations in intensity of the reflected light are recorded by a mirror galvanometer. The author used this method with infra red light for the reflexes of the pupils. He suggested application of this method for the measurement of the pulse rate at the Vena Jugularis. The main difficulty however is the immovable fixture of the registration apparatus to the neck of the subject.

In 1942 Schwarzschild and Shelesnyak (20) improved their pulse counter. Instead of an electromagnetic counter they used now a gas filled tube discharging a condenser at each heart beat. As this discharging depends too much upon the shape of the input wave it is not measured, but used to set off the discharge of a second gasfilled tube. This second discharge current flows through a meter shunted by a condenser. The pointer of the indicator moves back to zero after each discharge making exact reading difficult.

Various kinds of work are examined by E.A. Müller (21) with respect to their fatiguing. As a measure for fatiguing he took the relation pulse rate - oxygen uptake. The following row shows an increasing fatiguing factor: cycling, mountaineering, weight lifting, handwheel turning, milking, mowing.

Wood, Lambert, Baldes and Code (22) described the influence of acceleration on arterial pressure, pulse rate, vascular filling degree , respiration and consciousness.

In the pulse rate meter of Sturm and Wood (23) again the R top of the electrocardiogram is used. In order to obviate false readings the amplifier is tuned at 15 cycles per second and in each individual case the location of the electrodes is determined experimentally in order to get the optimal heart action potentials with a minimum of skeletal muscle potentials. As the condenser to be charged is connected permanently to the vacuum tube voltmeter, the pointer of the indicating instrument will move back to zero at each discharge of the condensor making exact readings difficult. The battery supply and the laborious adjustments are serious disadvantages.

Suckling (24) detected the movements of the Arteria Radialis by a piezo electrical crystal. A condensor is charged between every two systoles and the end voltage is transferred on to a RC combination by means of an electromagnetic relay. A vacuum tube voltmeter is placed behind this RC combination. The meter indicates the mean value of the pulse rate and only slow variations are reproduced. Muscle tensions in the neighbourhood of the pulse cuff are bound to give artificial extra systoles.

Müller and Reeh (25) developed a pulse counter, in which the heart beat is detected optically. A selenium photocell and a light bulb are clipped at the ear. The potential variations at the photocell are amplified and control a gasfilled triode. A telephone counter is inserted in the anode lead of this triode. The dial is photographed every minute. By subtracting from each number the preceding number, the mean frequency over a minute is attained,

The pulse rate meter of Boyd and Eadie (38), too, uses the action potentials of the heart. This meter is constructed especially for pharmacological experiments on animals. The amplifier is followed by a frequency selective stage, tuned at 15 cycles per second. A disadvantage is again the laborious readjustment of the apparatus before each experiment.

3. PROPOSITION

The aim was to develop an instrument indicating or recording during a given time the pulse rate of a subject performing exercises. A study of the above described pulse rate meters will make clear that they all are showing one or more disadvantages, making them unsuitable for this particular purpose.

Some of them are not pulse rate meters at all, but only pulse counters (9), (11), (12), (15), (20), (25).

Others are unfit for use with subjects performing exercises (2), (4,6), (13), (15), (16), (20), (23), (24).

Some methods of frequency measurement have a serious disadvantage, viz. the pointer of the indicator moves back to zero between two systoles, thus making exact reading impossible (20), (23), (24).

It is important that the operation of the apparatus requires a minimum of the attention of the experimentor. The pulse rate meter of Sturm and Wood (23) e.g., is difficult to accept as this meter requires readjustments from case to case.

Thus we decided to develop a pulse rate meter, which

1) gives the pulse rate as a direct meter reading;
2) makes it possible to record the pulse rate on a film;
3) fits for use on subjects performing exercises;
4) requires a minimum of the attention of the experimenter.

4. DETECTION OF THE HEART BEAT

A pulse rate meter will have to measure the time intervals between every two consecutive heart beats, this time interval being a linear reciprocal function of the pulse rate. It is convenient doing this interated time measurement electrically. The apparatus has to be supplied with a pick up, detecting one of the ways in which the heart beat reveals itself and transforming it into some electrical magnitude suitable for further digestion.

As demonstrations of the heart beat to be considered for detection, we can mention:

1) the action potentials of the heart;
2) the heart sounds;
3) the variations in the degree of filling of the blood vessels.

1) Though the heart action potentials have the attractiveness of being already electric phenomenons, thus making transformation superfluous, the shape of the electrocardiogram shows, that it will be difficult to develop a pulse rate meter measuring the frequency at the heart action potentials. The instrument would have to discriminate not only between the R top and the T top (eventually the P top) of the electrocardiogram, but also between the action potentials of the heart and those of other muscles.

2) Employing the heart sounds includes the use of a pick up discriminating between the vertex beat and each of the heart sounds. This pick up has to be insensible to breathing noise and any sound arising from the environment. The fixation of a microphone on the chest of a subject performing exercises will lead to great difficulties.

3) The variations in the degree of filling of the blood vessels can be detected plethysmographically and photo-electrically. In volume measurements immovable fixture of the part of the body to be measured is a fundamental requirement.

The photo electric measurement of the degree of filling of the blood vessels offers the best prospects at the determination of the pulse rate of a person performing exercises. From the literature we know oxymeters, pulse counters and circulation time meters taking the signal off the lobe of the ear. The ear fits quite well for radiation of light through it, whilst as there is a minimum of muscle tissue in the ear, no disturbances are to be expected due to muscle movements. For these reasons we went into a more thorough examination of this method of detecting the heart beat at the possibility to serve as starting point of frequency measurement. It turned out to be important to fix the photocell and the light source upon the ear in such a manner that mutual sliding is prevented. For this purpose a disk of perspex is interpolated between the ear and the light source. With this disk and a steel spring the photocell and the light source are clinged to the ear thus preventing any sliding, while the blood circulation in the exposed part of the ear is not hindered. Besides this piece safeguards the ear for excessive heating.

The pulsation of the blood flow causes a saw tooth shaped potential over the load resistance of the photocell. Figure 1 shows a few examples of the potential over the load resistance of the photocell as a function of the time. The curves are taken from different persons and recorded with constant sensitivity of the registration apparatus. The figure shows that the shape and the amplitude of the curves varies for different persons. In pathological cases we can expect much greater deviations than those shown here. Nevertheless these potentials always show a distinctly saw tooth shaped nature. Whereas a saw tooth shaped potential fits extremely well as starting point for electronic frequency measurement, this method of detection of the heart beat was chosen.

5. GENERAL ARRANGEMENT

5.1 Introductory

The normal pulse rate of man at rest is about 70 beats per minute. Under various circumstances, as there are the consumption of food, performance of exercises, or in consequence of emotions the pulse rate increases. The pulse rate decreases, e.g. during sleep or under narcosis.

A frequency range of 50 till 200 beats per minute was chosen as the described pulse rate meter was meant particularly for physiological investigations in cardiae changes during exercises.

This frequency range can be altered easily when required.

There are various ways to measure frequencies electronically. The measurement of very low frequencies can be done indirectly with the aid of a condenser being charged and discharged periodically. The pulse rate in the reciprocal value of the duration of the interval between two consecutive systoles. The voltage across a condenser being charged during this interval by a controlled current will be a measure for the duration of this interval. Repeating this charging and discharging periodically, viz. discharging the condenser quickly at the beginning of a systole and then charging it till the next systole, will produce a voltage, which value, immediately before the discharge, will be a function of the pulse rate.

If we succeed in transposing this voltage into a meter deflection, we may calibrate this deflection directly in beats per minute and the pulse rate meter is realized.

5.2 Block schematic diagram

The general arrangement and action of the instrument will be discussed with the aid of a block schematic diagram.

Figure 2 shows the block diagram. The pick up device is a photo electric cell. The varying potential across the load impedance of the photocell is applied to a three stage amplifier. The amplifier has a frequency range from about one half till about 30 cycles per second. The frequency of the mains supply is attenuated excessively.

We already saw how both shape and amplitude of the saw tooth shaped signal may vary. In figure 8 two saw teeth are shown, having like frequency, but differing in shape and amplitude. One might use these potentials to control a relay. It can be arranged thus, that when the amplitude of the signal reaches a certain value, e.g. the level e in figure 8, a relay is actuated and makes a contact. The contact is broken again, when the amplitude of the signal is lowered till below the level e. A condenser may be charged through this contact. However, figure 8 shows that two signals of like frequency but differing in shape will give different charging times (compare t_1 and t_2) thus giving no exact relation between the frequency of the signal and the voltage across the condenser. That is why it is necessary to insert a triggering circuit between the amplifier and the relay. This triggering circuit transforms the saw tooth shaped signal into constant pulses, the mutual distance of these pulses is a measure for the frequency of the signal, independent of the shape or the amplitude of the signal. These pulses occur at the moment the voltage is lowered till the level e in figure 8.

A condenser is charged and discharged periodically via a relay system with the aid of these pulses. At the end of the charging period, just before the discharging, the load of this condenser is transferred on to a second condenser. The voltage across the first condenser between two systoles is increasing from a certain initial value till the terminal value corresponding with the time interval between these two systoles and then diminishing quickly. The voltage across the second condenser, however, remains constant during this time interval and is equal to the terminal voltage of the first condenser in the preceding interval. If the frequency does not alter the first condenser will be recharged till the same terminal voltage, and the voltage across the second condenser remains unchanged.

In doing so the direct indication of the pulse rate is realized. The voltage across the second condenser is measured by a vacuum tube voltmeter having a very high input impedance in order to obtain a neglectible load of this condenser. The measured frequency is indicated by a milliammeter. A recording device can be put in series with this meter.

5.3 Action

A further explanation of the various transformations of the signal from the photocell will be given with the aid of figure 5. Figure 5a shows the output signal of the photocell in its simplest form for two different frequencies. Figure 5b represents the same signal after amplification. This signal, in figure 5c indicated by a thin line, is the input signal of a bistable trigger. A bistable trigger is a circuit with two stable states. Two different output voltages are corresponding with these two stable states. If the input voltage of such a circuit rises above a certain level the output voltage rises rapidly from its lower to its higher value. On lowering the input voltage below this level the output voltage flops back to its lower value. In this way the saw tooth shaped signal is transformed into a square wave. The duration of this rectangle is not yet a measure of the frequency, since this duration still depends on the shape and the amplitude of the signal. The distance between two similar slopes of this square wave, however, is a measure for the frequency. In order to discriminate between the downward and the upward slopes, the squaresare differentiated (figure 5d). Sharp positive pulses arise instead of the upward slopes, sharp negative pulses instead of the downward slopes. The desired discrimination is obtained by cutting off either the positive or the negative pulses. We have to cut off the positive pulses since the next trigger is to be actuated by negative pulses, as we will see later on. The result is shown in figure 5e. Attention is drawn to the fact that the distance between two consecutive pulses is the reciprocal function of the frequency of the original signal. These pulses mark the beginning and the end of each interval.

A certain time is needed for the discharging of the condenser. This time, diminishing the charging time, must be constant in order to obtain a well defined frequency measurement. With the aid of a monostable trigger the negative pulses of figure 5e are transformed into squares of constant duration. A monostable trigger is a circuit with one stable state. When a negative pulse is impressed on the input of such a circuit, the output voltage rises rapidly from its stable lower value to a certain predetermined higher value, and falls back to its stable lower value after a certain time depending on the RC time constant of the trigger. In doing so the negative pulses are transformed into squares of constant duration (see figure 5f). These squares are used to discharge the condenser at the end of the interval (figure 5g).

6. LIGHTSOURCE AND GENERATOR

As lightsource a normal incandescent bulb (6 Volts, 0.35 Amp.) was used. Feeding this bulb with alternating current of 50 cycles would give a 100 cycles component in the emitted light due to the low heat capacity of the filament. The signal at the load resistor of the photocell will contain a 100 cycles component too. As this disturbance is a few times greater than the desired signal it is difficult to eliminate the first without considerable attenuation of the latter. Although rectifying and smoothing of the alternating current is possible, it is preferable to feed the bulb with a high frequency alternating current. A frequency of about 100 kc was chosen. As the heat capacity of the filament is sufficiently large at a frequency of 100 kc, there is no 200 kc component to be expected in the emitted light. Besides elimination of this frequency far outside the used frequency range is quite simple.

Excessive heating of the ear is prevented partly by interpolating a polyvinyl disc (see figure 21), partly by metallising the glass of the bulb. In this metal coating, reducing the direct radiation of heat at the ear and stimulating the heat conduction towards the fitting, a small aperture is made such that the emitted light beam is directed at the photocell.

As a generator circuit a modification of the Meissner circuit was chosen. Figure 4 shows the diagram. The oscillation is obtained by inductive feed back of the anode circuit of the EL 41 to the grid circuit. To increase the efficiency the anode circuit is tuned. A filter consisting of a self inductance of 200 mH and a condenser of 0.1 μF prevents the high frequent oscillation from backing up into the common power supply. The three honeycomb-coils are wound jointly on a circular former of insulating material. Inside the former a ferroxcube core is mounted movably in order to provide readjustment of the power supplied to the light source. The required anode voltage of the generator is derived from the common stabilized power supply. The stability of the generator appeared to be such that the light intensity could be considered to be constant.

7. PHOTOCELL AND CHECKING CIRCUIT

We chose a Philips photocell, type 3530, a gasfilled cell with caesium cathode. This cell has a, for this purpose sufficient, sensitivity for red light. Dimensions and weight are reduced by taking off the base. The required tension (90 Volts) is taken off the common stabilized power supply through a potentiometer and a low pass filter (see figure 3). A condensor (15000 pF) is placed in parallel with the load resistor (3M Ω) in order to prevent any disturbance of the amplifier by the high frequency supply of the light source.

By means of a switch either the photocell, or the checking circuit can be connected to the input of the amplifier. This circuit serves to verify the right operation of the apparatus. A checking square wave of 80 or 160 pulses per minute can be obtained. These values were chosen because they are distributed reasonably over the used frequency range of 50 till 200 beats per minute. The checking circuit consists of a self starting synchrone motor, propelling a shaft at a speed of 80 revolutions per minute. To this shaft two disks are keyed respectively with one and two cams. These cams make and break a contact thus impressing periodically a voltage on the input of the amplifier. This voltage is taken from the common stabilized power supply via a potentiometer.

8. AMPLIFIER WITH FILTER

The amplifier has to meet the following requirements:

1) The frequency characteristic has to be such, that saw tooth shaped potentials of a fundamental frequency from $\frac{1}{2}$ to 3 cycles per second are amplified sufficiently.
2) Potentials in the order of $\frac{1}{2}$mV have to be amplified till about 40 Volts. The amplification factor has to be about 80.000.
3) The amplifier has to be completely mains fed. The action of the amplifier may not be affected by variations of the mains supply.
4) Interferences are to be eliminated.

In amplifying these extremely low frequencies the push pull amplifier offers many profits as this type of amplifier is less sensitive to variations in the power supply and decoupling of the cathode and screen grid is not necessary (27), (28).

The amplifier (see figure 6) consists of three push pull stages followed by a parallel T filter.

The first stage contains a double triode ECC 40 employed as a cathode follower (29) (32), thus attaining two equal but opposite signals to be impressed on the control grids of the next stage (twice EF 40). Since in this case the common cathode resistor is large (33 k Ω) a constant positive voltage has to be applied to the grids in order to obtain the correct operating conditions. This bias voltage is taken off the stabilized common power supply through a potentiometer and a double smoothing filter (twice 2 MΩ and 12.5 µF).

The coupling elements have been chosen such that sufficient amplification could be obtained for the lowest frequency used. The shunt condenser at the in- and output of the amplifier and the parallel T filter are limiting the frequency characteristic up to about 30 cycles per second.

The parallel T filter (31), (32) has its resonance frequency at 50 cycles per second thus eliminating any interference effectively (the European mains supply has a frequency of 50 cycles per second).

The tubes are adjusted such that an overall gain of 160.000 is obtained. As the transmission factor of the parallel T filter is as much as $\frac{1}{2}$, an input signal of $\frac{1}{2}$ millivolt at the loadresistance of the photocell results in about 40 Volts at the first grid of the bistable trigger.

9. MAIN TRIGGERS

The circuit next to the amplifier consists of three parts, viz.:

1) the bistable trigger
2) the differentiator
3) the monostable trigger

These circuits, shown in figure 9, will be briefly discussed (33). The grid of the first triode of the bistable trigger has a negative bias. This negative bias nearly cuts the anode current of the first triode, this tube is off. Due to this the anode voltage of the first and the grid voltage of the second triode are high. The second triode takes a large anode current - this tube is on - the anode voltage of the second tube (the output of the trigger) thus being low. The first grid receives its signal from the parallel T filter.

If because of this signal the grid voltage is increased till a certain praeadjustable level the anode current will show a sudden rise. This causes a rise of the cathode voltage, whilst the anode voltage and at the same time the grid voltage of the second triode will fall, thus cutting off the anode current of the second triode. The output voltage shows a sharp rise. Lowering the voltage of the first grid till beneath the forementioned level will cause a reverse action: the first tube goes off again, the second on, the output voltage falls back to its lower value. In this way we have transformed the saw tooth shaped signal into a square wave.

The output signal of the bistable trigger is differentiated with the aid of a condenser of 1 kpF and a resistance of 500 kΩ, that means the square wave is transformed into two sharp pulses, a positive one corresponding with the upward slope of the square and a negative one corresponding with the downward slope (compare figure 5c and d).

The diode EA 50 is placed thus as to cut off the positive pulses. In figure 5c the base line is drawn as a straight line, but in practice irregularities may occur. In order to avoid any reaction of the next trigger due to these irregularities a positive bias is impressed on the diode with the aid of a resistance of 2 MΩ. Due to this the cutting action starts beneath the base line making sure only the required negative pulses are to reach the input grid of the next trigger.

The next trigger is monostable. In the stable state the first tube is on since the cathode is connected directly to earth and the grid has a positive bias. The anode voltage of the first triode (the output voltage of this trigger) is low. The second triode is off since the grid bias is low and the cathode has a positive bias. The impression of a sharp negative pulse on the grid of the first triode will cut off the anode current causing a sudden rise of the output voltage. Since the grid voltage of the second triode follows this increase its anode voltage will decrease. The grid of the first triode is connected to the plate of the second triode by means of a 10 kpF condenser. It depends on the time constant of this condenser and the grid leak how long it lasts before the grid voltage of the first triode has risen sufficiently to restore the stable state of the trigger.

Thus at the output of this trigger a square pulse arises with a constant duration, which corresponds with the time the first tube is off.

10. CHARGING CIRCUIT AND MECHANICAL RELAY

The monostable trigger produces pulses of constant duration and height having mutual distances equal to the time intervals between two consecutive heart beats. With the aid of a mechanical relay system we can use these pulses to control the charging and discharging of a condenser and the transfer of the endpotential from this condenser on to a second condenser, connected permanently to a vacuum tube volt meter.

In figure 11 the diagram of the charging circuit and the mechanical relay is given. The anode current of the twintriode ECC 40 flows through the coil of relay 1. The cathode resistance consists of a gasfilled tube (85 A 1) fed by a resistance of 120 kΩ. This neon tube is keeping the cathode potential constantly at 85 Volts. The grid of the triode is connected to the output of the monostable trigger of figure 9, via a potentiometer. When there is no pulse at the output of the trigger the grid has a large negative bias with respect to the cathode. In this case no current is flowing through the valve. When the monostable trigger produces a pulse the grid potential increases and allows an electron current to flow through the tube, thus actuating relay 1. The contacts a and b are closed simultaneously and remain closed as long as relay 1 is actuated. By closing contact a relay 2 is actuated. The contact c and d are adjusted in such a manner that within the time of the downward stroke of the relay, contact c is made and broken again before contact d is made. During the further time in which relay 2 is actuated, c remains open and d closed. In the time of the upward stroke c is made and broken again. In the downward stroke of relay 2 contact c connects the 12 μF condenser with the 0.005 μF condenser via the closed contact b. Since the 0.005 μF condenser is small compared with the 12 μF condenser, the voltage across the first will become equal to the voltage across the latter. After the contact c is broken, the 12 µF condenser is discharged via contact d and the 10 Ω resistor.

When the square pulse impressed on the grid of the triode disappears, relay 1 breaks the contacts a and b, thus causing relay 2 breaking contact d. During the upward stroke of relay 2 contact c is closed, but since contact b is open the 0,005 µF condenser is not connected to the, meanwhile discharged, 12 µF condenser and keeps its charge until the next square pulse.

The desired frequency range determines the magnitude of the charging current. This current depends on the dimensions of the charging circuit. Apart from the frequency range the distribution of the frequencies over bet scale may be adapted to any special requirement by a suitable choise of the components of the charging circuit.

In figuro 5g the voltage across the condenser during an interval is drawn as if it was a linear function of the time. In this case the scale division would become linear, if not a constant part of each time interval had to be used for the relay switching. The consequence is that the scale is shrinking in the higher frequencies.

In the case on hand it was desirable to expand the scale in the middle of the frequency range, since these frequencies are the most interesting in the experiments on subjects performing exercises. This was achieved by charging the condenser via a parallel connection of a triode and a resistor. In doing so the shrinking of the scale at the upper end of the frequency range was diminished as well.

It is possible to obtain a fairly constant charging current by means of a pentode and a exponential decreasing current by means of a resistor. The charging current through a triode is an intermediate form of these two. By varying the magnitude of the internal resistance of the triode and the value of the shunt resistor a large diversity of charging curves can be obtained. Figure 14 shows the scale division of the discussed pulse rate meter.

11. ELECTRONIC RELAY

11.1 Introductory

In certain cases the use of a mechanical relay in the pulse rate meter might prove a disadvantage, viz. the beating of the mechanical relay is audible. This beating inherent to the rhythm of the heart beat of the subject will affect him psychically. Since in this case it was preferable to use a noiselessly working pulse rate meter, we tried to find an electronic equivalent of the mechanical relay.

Proceeding from the square pulse of the monostable trigger it was possible, with the aid of a mechanical relay, to realize the mutual connection of the condensers and the discharging of the 12 µF condenser. In the electronic modification however we need two square pulses, proceeding shortly after one another. For this purpose two auxiliary triggers are inserted.

11.2 Auxiliary triggers

Figure 10 shows two monostable triggers to be connected to the monostable trigger of figure 9, Thus we have obtained three monostable triggers connected in series jointed by differentiating sections. From this series of triggers three positive square pulses arise, linked closely to each another in time, that is to say the downward slope of the first coincides with the upward slope of the second pulse, the downward slope of the second with the upward slope of the third. Between the first and the third pulse a time interval has given by the breadth of the second pulse. Using the first and third pulse we have obtained two square pulses, proceeding shortly after one another.

11.3 Charging circuit and electronic relay

The charging circuit in the electronic modification is identical to the charging circuit of the mechanical relay. In figure 12 this charging circuit is added for the sake of completeness.

The twin triode 6SN7 serves to make and break the connection between the 12 µF and the 0.005 µF condenser. The two triodes are connected back to back, that is to say the anode of one triode is connected to the cathode of the other triode and vice versa, whilst the grids are joint together. The glow temperature of the cathode is decreased by placing a 10 Ω resistor in series with the filament of this tube. The pentode UL 41(used as a triode) takes care of the short circuiting of the 12 µF condenser. The square pulse originating from the first monostable trigger is impressed on the grids of the twin triode, the square pulse originating from the third monostable trigger on the control grid of the pentode. Since a short time elapses between the occurrence of these two square pulses it is attained that the connection between both condensers is broken before the discharge of the 12 µF condenser begins. The points x and y are connected with one plate of the 12 µF, respectively the 0.005 µF condenser. The other plates of these condensers are connected jointly to the stabilized power supply of +200 Volts. Depending of the charge of these condensers the potentials of the points x and y may vary from about 150 Volts till about 200 Volts in respect to chassis. The joint grids are connected to the first anode of the first monostable trigger. In the stable state of the trigger this anode has a potential of about 60 Volts. The grids of the twin triode have a large negative bias as well in respect to the anode as to the cathode; this tube is off.

Measurements showed that even with this high negative grid bias a troublesome leakage current may occur. It is easy to calculate that if the 0.005 µF condenser is to keep its charge unchanged during the time interval between two systoles even at the lowest frequencies, that is to say if the pointer of the indicator has to be at rest during that interval a maximum leakage current of about 10^{-11} Ampères is to be tolerated. For this reason the twin triode has to be selected.

When a square pulse occurs at the output of the first monostable trigger, the grid voltage will increase by about 100 Volts making the twin triode conductive in both directions. In case of different voltages across the condensers (on changing the frequency) a balancing current will flow between the points x and y making the voltage across the 0.005 µF condenser equal to the end voltage of the 12 µF condenser.

The series resistance (2.2 MΩ) in the grid circuit serves to limit any grid current and to decrease the load of the trigger. The RC element (1 MΩ - 0.1 μF) decreases the capacitive coupling between the grids on one side and the cathodes and anodes of the twin triode on the other.

The square pulse from the third monostable trigger, occurring shortly after the square pulse of the first trigger, makes the tube UL 41 conductive in order to discharge the 12 μF condenser.

Attention may be drawn to the fact that the conductance of the electronic relay is smaller than that of the mechanical relay where a connection with zero resistance is obtained. Consequently the pulse rate meter with electronic relay will not follow instantaneously a sudden change in frequency. As a result of this an extra systole will be indicated only qualitatively.

12. VACUUM TUBE VOLT METER

As already is explained the vacuum tube voltmeter is not to take any current off the 0.005 μF condenser. For this reason a cathode follower circuit was chosen (34) and put in push pull in order to minimize the influences of variations in the power supply (see figure 13).

Since the moving coil meter is connected between the two cathodes the current to flow through the meter is not flowing through the tubes. In doing this the tubes are adjusted at minimum anode current, i.e. large negative grid bias. As this implies, that the resistance between the grid and the cathode is large, the load across the 0.005 μF condenser is neglectible. In the grid and plate leads resistances of 1 kΩ are inserted. To cancel any difference in the internal resistance of both triodes a correction resistance may be placed in one of the cathode leads. A zero adjustment is provided by means of a potentiometer connected to the grid of the second triode.

The series resistance of the moving coil instrument is chosen such that a variation of the meter current from 0 to 100 μ Amp. agrees with the maximum potential difference across the 0.005 μF condenser.

13. POWER SUPPLY AND STABILIZATION

The apparatus is mains fed and the required anode voltages derived from the rectifier valve AZ 41 are stabilized electronically. Figure 15 shows the arrangement. Instead of the normal L-C smoothing circuit just one electrolytic condenser is used.

The stabilizing circuit consists of a variable series resistance (UL 41), two control pentodes (EF 40) in push pull and two gasfilled tubes 85A1. (35), (36)

Point a of the potentiometer consisting of a resistance of 90 kΩ and a neon tube 85A1 has a constant potential (85 Volts). This potential acts as a reference voltage and is applied to the control grid of one of the pentodes. Behind the variable series resistance (UL 41) a potentiometer is formed by two resistances respectively 220 kΩ and 70 kΩ. In equilibrio point b has likewise a potential of 85 Volts. Increase of the output voltage - whatever the reason may be - causes an increase of the grid voltage of the second control pentode and thus an increase of the anode current. Hereby the voltage in point c, i.e. the grid voltage of the UL 41, will decrease. In consequence of this the internal resistance of the UL 41 increases and cancels the increase of the output voltage. In case of a decrease of the output voltage the reverse process occurs.

This control works instantaneously, whereas moreover a forward control consisting of a resistance of 15 MΩ and a condenser of 100 pF, is inserted. This forward control is connected before the series resistance UL 41, so that variations in tension do not need to appear at the output of the stabilizing circuit in order to be stabilized.

With the aid of the first mentioned potentiometer (220 kΩ, 70 kΩ) the output voltage is adjusted at the desired value. These values already assure a certain stabilization. A higher degree of stability is obtained by a proper choice of the value of the resistance of the forward control. In connection with already existing, unavoidable capacitances two capacitators, respectively 0.1 μF and 100 pF are employed in the control circuit in order to stabilize the mains frequency.

Variations in the load are stabilized with the aid of a resistance of 10Ω inserted in the minus lead of the smoothing circuit. In case of an increase in load the voltage drop over this resistance will increase thus making the grid bias of the second control pentode more negative and keeping the output voltage constant.

Since the vacuum tube voltmeter needs a stable supply of 200 Volts a cathode follower (EF 42) is placed at the output of the stabilization circuit providing this voltage (37).

In consequence of the high demands put on the input resistance of the vacuum tube voltmeter it is necessary feeding the filaments of the vacuum tube voltmeter and the electronic relay out of separate, excellently insulated, windings on the power transformer, thus preventing any leakage along this path.

14. CONCLUSION

A few drawings and pictures are added to elucidate the construction.

Figures 16 and 19 show the topchassis, containing the amplifier, the triggers and the checking circuit with switch. It should be noted that the input circuit inclusive the switch and the double triode of the first stage of the amplifier are screened thoroughly.

Figures 17 and 20 give respectively the arrangement and the picture of the bottom chassis, containing the power supply with stabilization, generator, electronic relay and vacuum tube voltmeter.

Figure 18 is a dimensional sketch of the frame.

Figure 21 gives some constructional details of the earclip with photocell, bulb and polyvinyl disc.

Figure 22 shows the earclip in situ. The four connections are lead to a clip on the mask with the aid of fine flexible wires and connected to the apparatus by a shielded cable of about 5 feet.

With reference to figure 23 the necessity of providing a good ventilation is emphasized, vide the ventilation holes in the cabinet.

Finally a picture (figure 24) is given of a complete arrangement as used in physiological investigations.

In many experiments in the field of the physiology of work and exercise it is important that the subject has a greater freedom of movement than is possible with a 5 feet cable. The possibility of disturbing interference when using a longer cable may be prevented by placing the first two stages of the amplifier, plus the generator for the light source in a separate box to be carried by the subject. Since the signal of the photocell is now amplified adequately there is no objection in connecting this pre amplifier by a very long cable with the pulse rate meter.

In order to obviate any disturbance due to variations in the day light a cap is to be placed over the ear thus preventing the direct light to fall on to the photocell.

15. REFERENCE LIST

1. Forbis, Prof. Ir R.J. — Cultuurgeschiedenis van Wetenschap en Techniek, pag. 237

2. Kraus, F. en Seelig, S. — Der Goldschmidtsche Pulsresonator Medizinische Klinik, 23 Jrg., no 18, Seite 670, 1927

3. Kraus, Prof. Dr F., Goldschmidt, Prof. Dr Ing R., Seelig, Dr S. — Analyse des Pulsrhythmus mit dem Pulsresonator Zeitschrift für die gesamte Experimentelle Medizin, Band 53, Seite 243, 1926

4. Fleisch, A. — Der Pulszeitschreiber Zeitschrift für die gesamte Experimentelle Medizin, Band 72, Seite 384, 1930

5. Fleisch, A. — Ueber das Verhalten der Pulsfrequenz bei seelischer Erregung, registriert mit einem neuen Zeitordinatenschreiber Archiv für die gesamte Psychologie, Band 87, Seite 532, 1933

6. Fleisch, A. — Die Registrierung zeitlicher Intervalle direkt als Ordinate mit dem Pulszeitschreiber Handbuch der Biologischen Arbeitsmethoden Emil Abderhalden, Abt. V, Teil 8, Seite 905, 1935

7. Fürstenberg and Hoffstaedt — Ueber vergleichende Untersuchungen mit dem Pulsresonator und dem Elektrokardiographen Klinische Wochenschrift, Jrg 8, no 31, Seite 1451, 1929

8. Goldscheider — Arhythmie und Pulsresonator Medizinische Klinik, Jrg 23, no 24, Seite 901, 1927

9. Boas, E. — The Cardiotachometer Archives of Internal Medicine, vol. 41, no 3, page 403, March 1928

10. Whitehorn, J.C., Kaufman, M.R., Thomas, J.M. — Heart rate in relation to emotional disturbances Archives of Neurology and Psychiatry, vol. 33, no 4, page 712, 1935

11. Henry, F. — An electric Cardiometer Science, vol. 86, no 2227, page 230, 1937

12. Djourno, A. — Sur la mesure instantanée de la fréquence du pouls
Paris Medical, Partie Medicale, CIX, pag. 183, 1938

13. Henry, F. — A direct reading cardio-chronoscope
Journal of Experimental Psychology, vol. 22, page 598, 1938

14. Tiitso, M. — Ueber die Methode der Registrierung von Pulsintervallen als Ordinate im Tierversuch
Pflügers Archiv für die gesamte Physiologie, Band 239, Seite 265, 1938

15. Laurence, Morehouse, Tuttle — An electric Pulscounter
The Journal of Laboratory and Clinical Medicine, vol. 24, page 1213, 1939

16. Matthes, K. — Ueber die Registrierung von Bewegungsvorgängen mit dem lichtelektrischen Reflexionsmesser
Klinische Wochenschrift, Jrg 20, Heft 12, Seite 295, 1941

17. Meyer, F. and Seidel, K. — Ueber die hämodynamische Bedeutung der Tachykardie bei der Kreislaufkrankheit
Klinische Wochenschrift, Jrg 20, Heft 19, Seite 469, 1941

18. Müller, E.A. — Die Pulszahl als Kennzeichen für Stoffaustausch und Ermüdbarkeit des arbeitenden Muskels
Arbeitsphysiologie, Band 12, Heft 1, Seite 92, 1942

19. Albers, D. — Untersuchungen über den Einfluss von dosierter ergometrischer Arbeit auf die Pulsfrequenz von Herzkranken
Arbeitsphysiologie, Band 12, Heft 1, Seite 15, 1942

20. Schwarzschild and Shelesnyak — A continuous electronic pulse rate indicator and recorder
Review of Scientific Instruments, vol. 13, page 496, 1942

21. Müller, E.A. — Der Pulsquotient als Mass der Muskelermüdung
Arbeitsphysiologie, Band 12, Heft 4, Seite 320, 1943

22. Wood, E.H., Lambert, E.H., Baldes, E.J., Code C.F. — Effects of acceleration in relation to aviation. Federation Proceeding, vol. 5, page 327, 1946

23. Sturm and Wood — An instantaneous recording cardiotachometer. Review of Scientific Instruments, vol. 18, no 10, page 771, 1947

24. Suckling — A cardiotachometer based on the plethysmogram. Review of Scientific Instruments, vol. 20, no 7, page 518, 1949

25. Müller, E.A. and Reeh, J.J. — Die fortlaufende Registrierung der Pulsfrequenz bei beruflicher Arbeit. Arbeitsphysiologie, Band 14, Seite 137, 1950

26. Pinxteren, J.A.C. — Hartmiddelen. Pharmaceutisch Weekblad, pag. 85, no 45/46, 11 November 1950

27. Johnston, D.L. — Electro-Encephalograph Amplifier. Wireless Engineer, vol. 24, page 231, August 1947

28. Parnum, D.H. — Transmission factor of differential Amplifiers. Wireless Engineer, vol. 27, pag. 125, April 1950

29. Bishop, P.O. — A high impedance input stage for a valve Amplifier. Electronic Engineering, vol. 21, no 262, page 469, December 1949

30. Geyger, W. — Der Katodenverstärker. Funk und Ton, Heft 3, Seite 119, 1948

31. Günther, Dipl. Ing. — Die Eigenschaften des Doppel-T-Vierpols zwischen endlichen Widerständen. Funk und Ton, Jrg 50, no 12, Seite 628, Dezember 1950

32. Givens, M.P. and Saby, J.S. — A simplified analysis of the parallel-T null network. Review of Scientific Instruments, vol. 18, no 5, page 342, May 1947; vol. 18, no 10, page 802, October 1947

33. Puckle, O.S. — Time Bases
London, Chapman and Hall Ltd, 1947

34. Taeger, W. — Der Katodenverstärker als Impedanzwandler
Funktechnik, no 16, Seite 444, 1951

35. Taeger, W. — Stabilisierung von Gleichspannungen
Funk und Ton, no 8, Seite 403, 1950

36. Benson, F.A. — Voltage Stabilizers
London, Electronic Engineering 1950

37. Willmore, A.P. — The cathode follower as a voltage regulator
Electronic Engineering, vol. 22, page 399, September 1950

38. Boyd, W.E. and Eadie, W.R. — A heart rate recorder for biological experiments
Electronic Engineering, page 102, March 1952

TNO
11-6-52
Lin

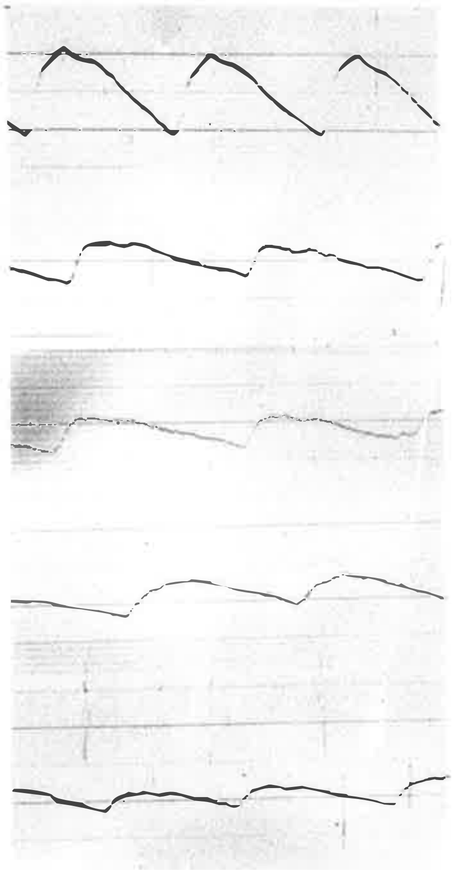


fig. 1 Zaagtandspanningen
fig. 1 Saw tooth potentials

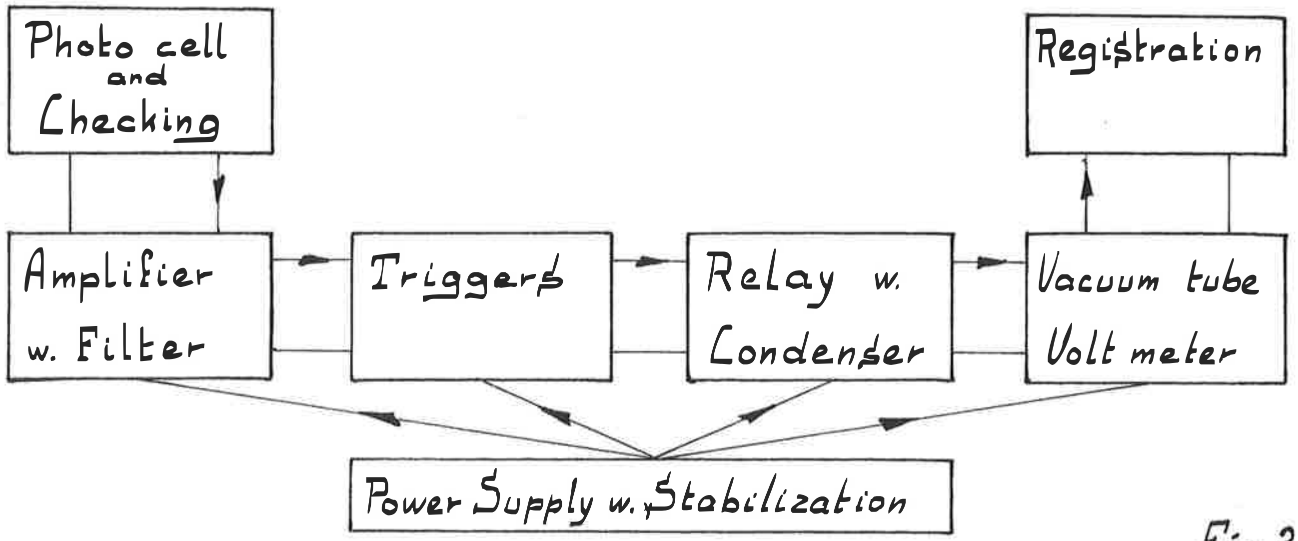


Fig. 2

Block Schematic Diagram.

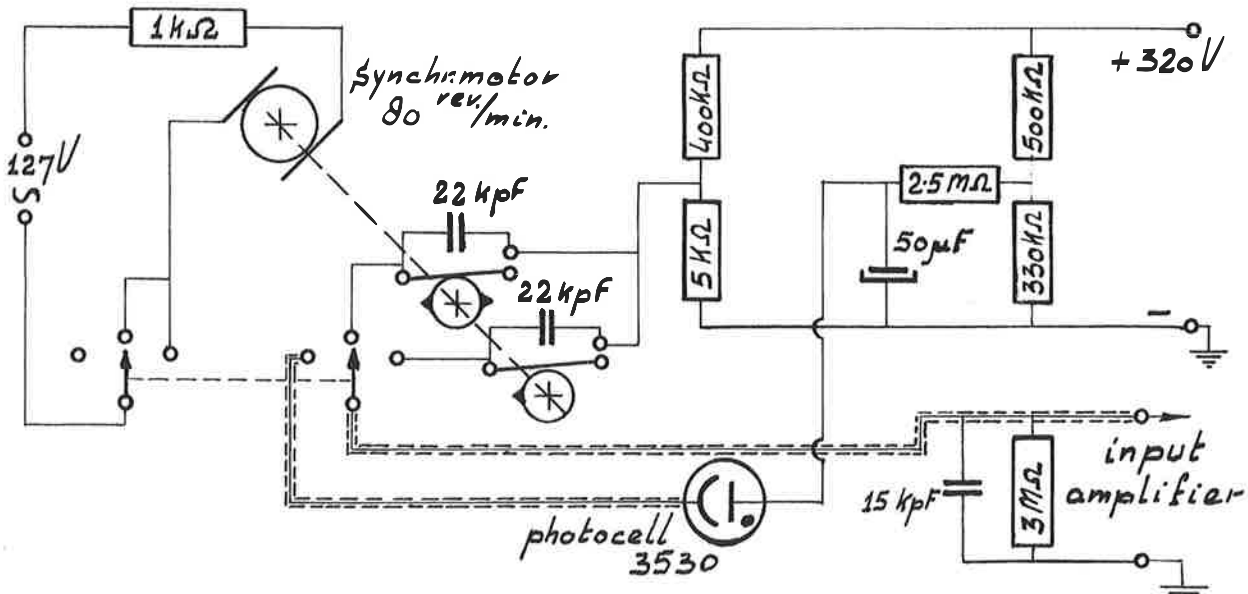


Diagram of Photocell and Checking circuit.

Fig. 3

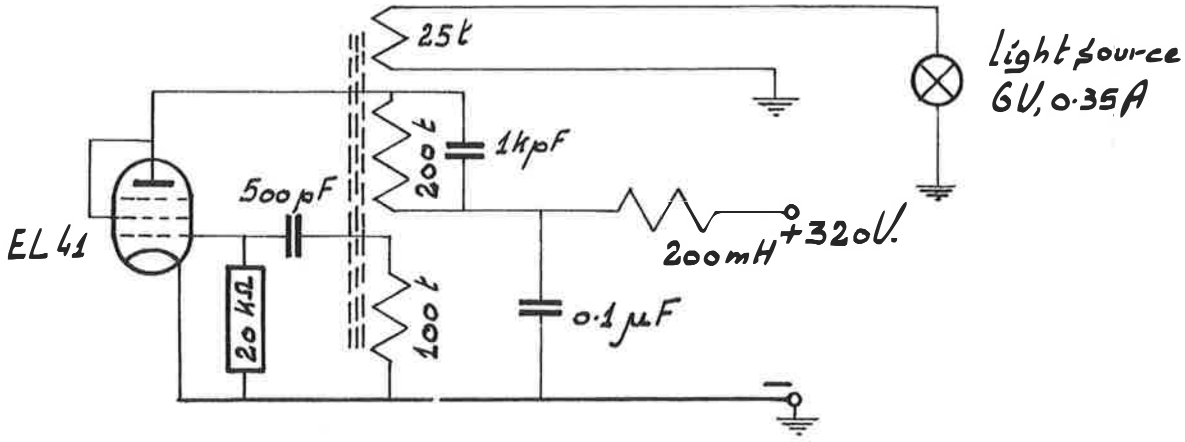
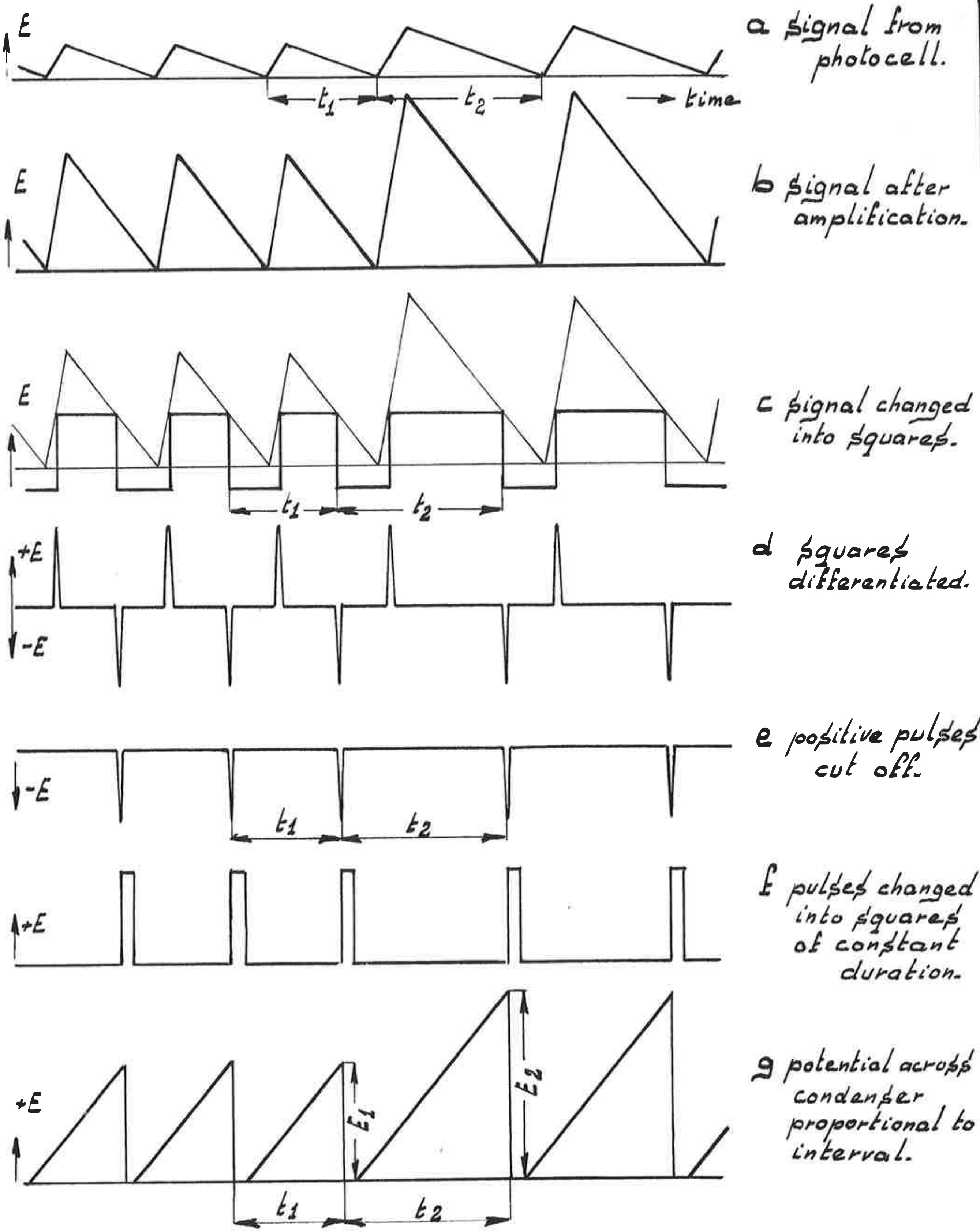


Diagram of Generator and Lightsource.

Fig. 4



Schematic Representation of the Action.

Fig. 5

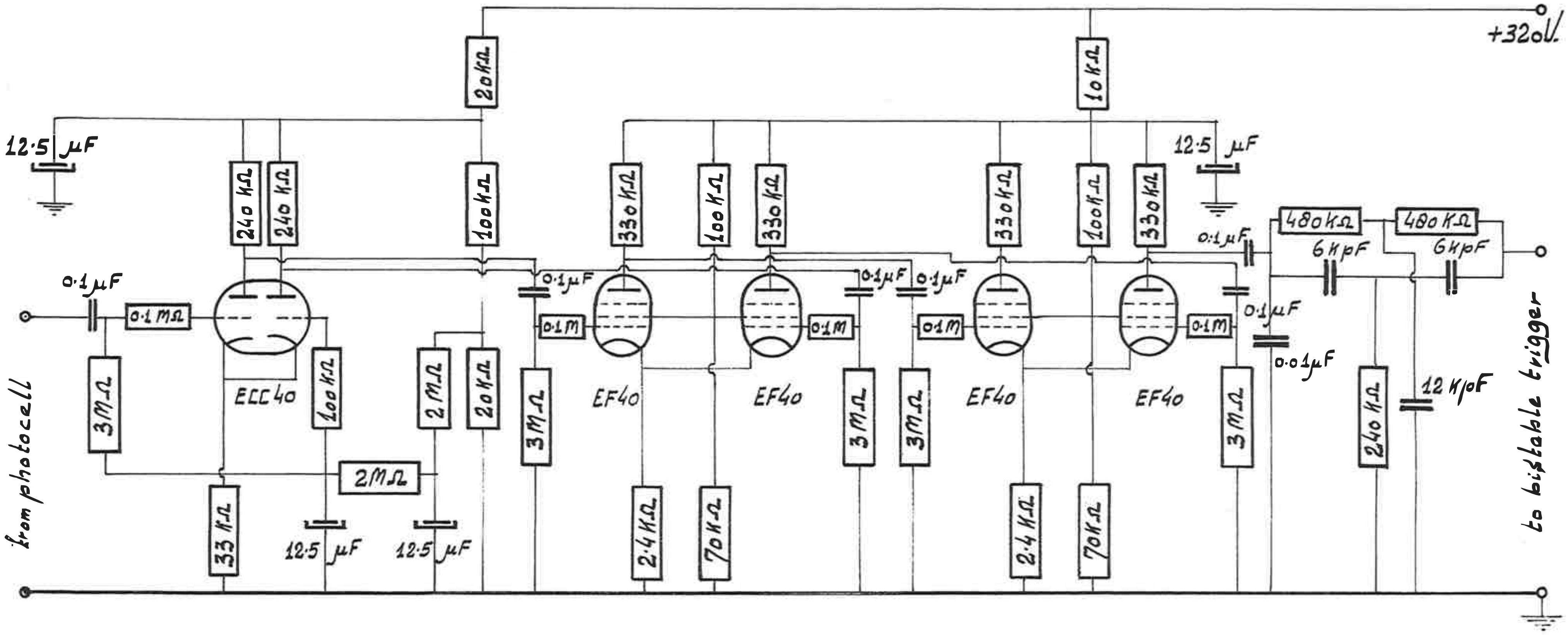
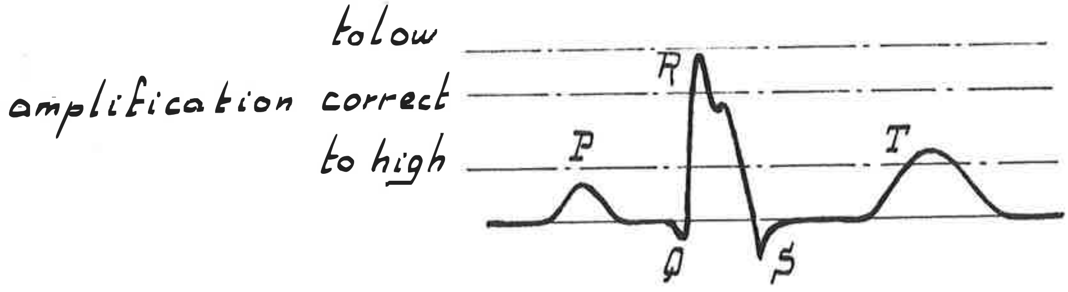


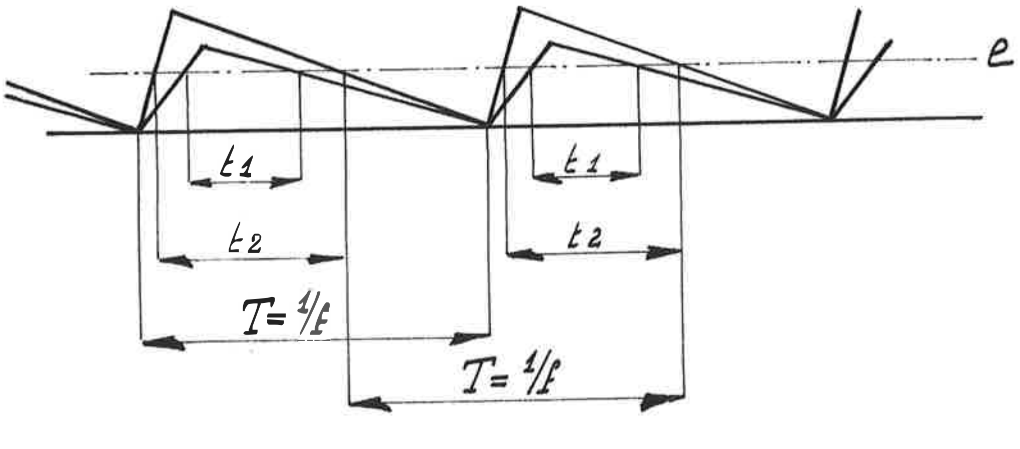
Diagram Amplifier with Filter.

Fig. 6



Electrocardiogram-

Fig. 7



Sawteeth of like frequency-

Fig. 8

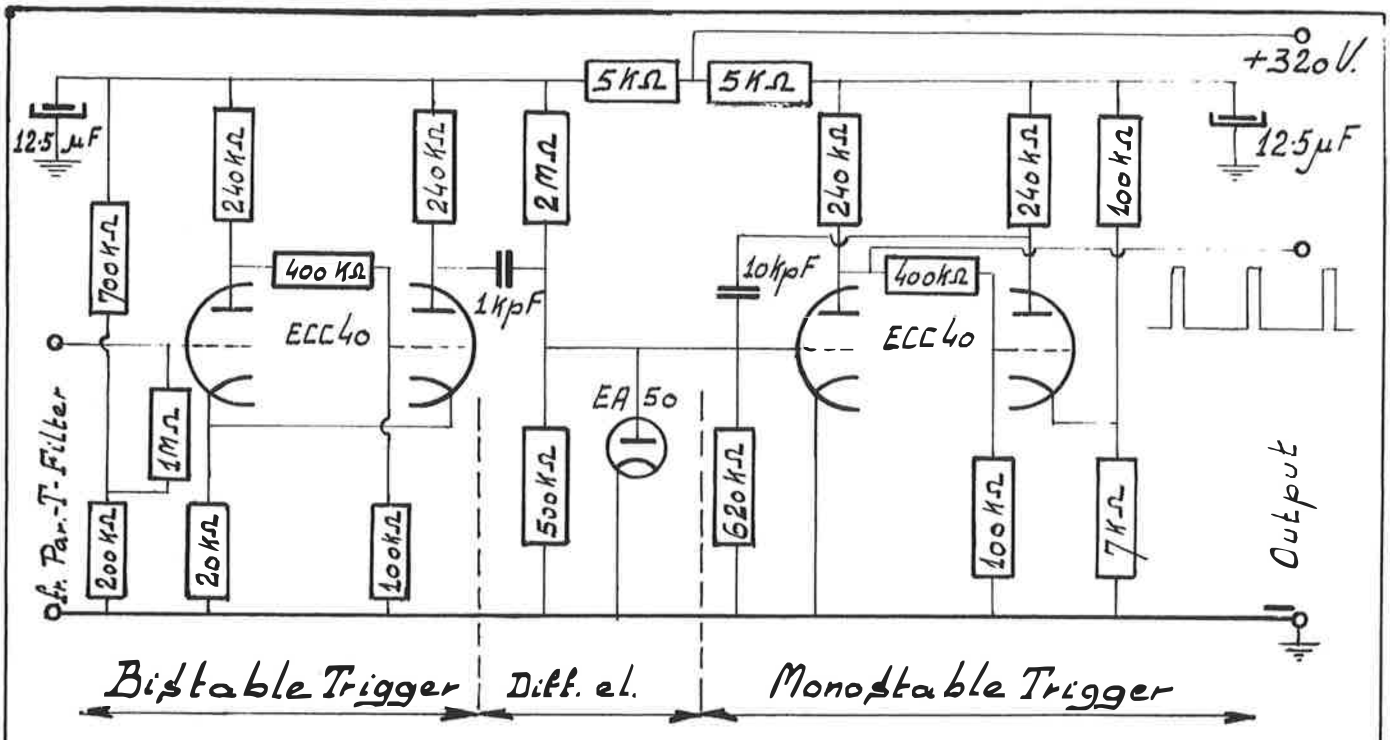


Diagram of Main Triggers.

Fig. 9

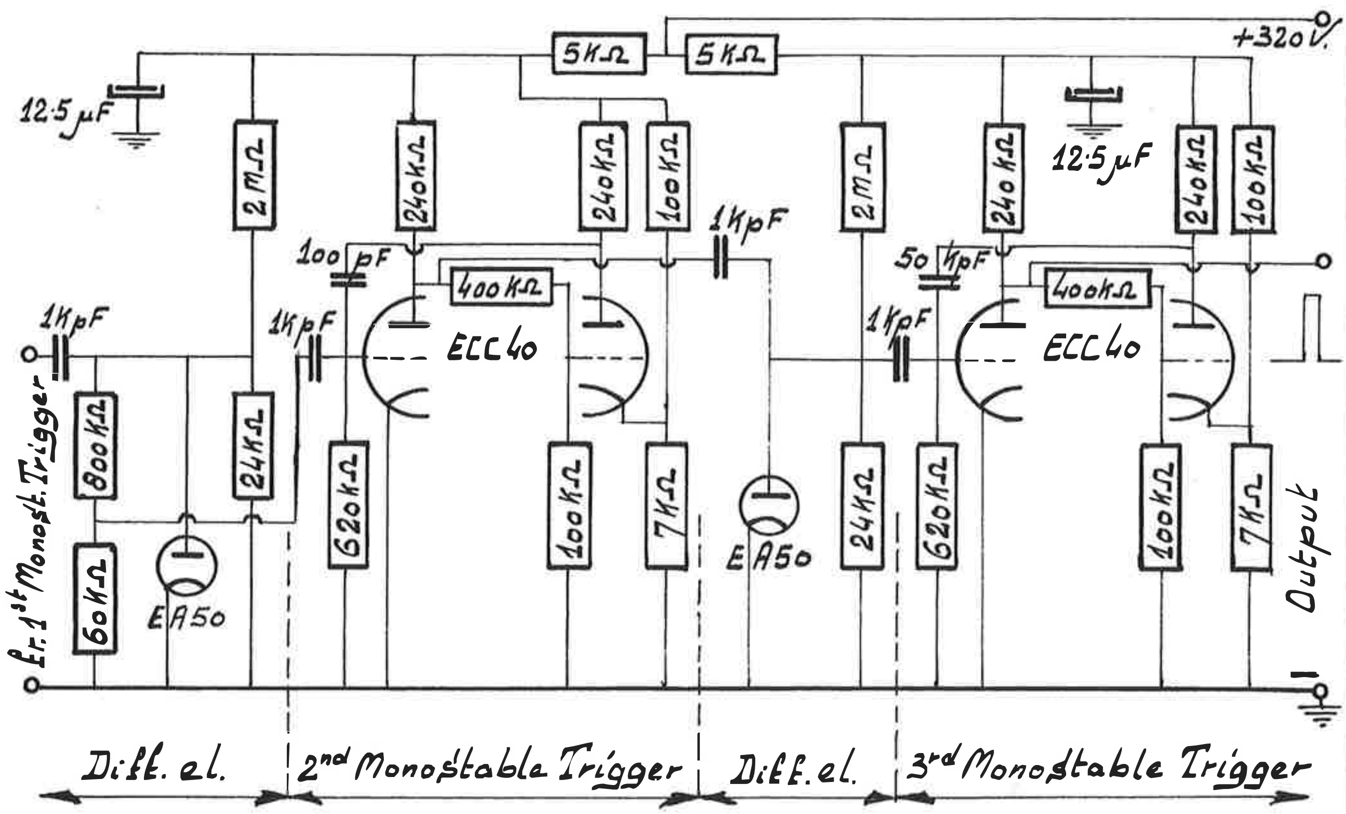


Diagram of Auxiliary Triggers.

Fig. 10

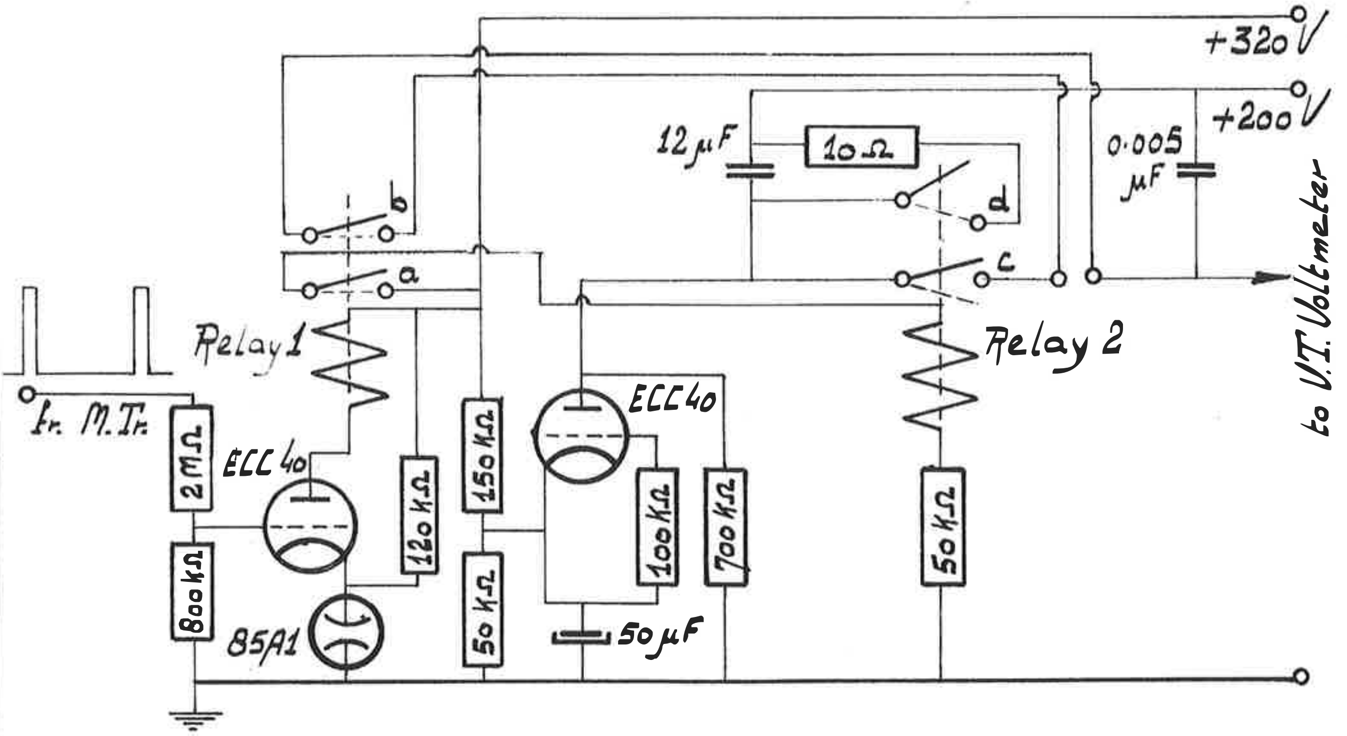


Diagram of Charging Circuit and Mechanical Relay.

Fig. 11

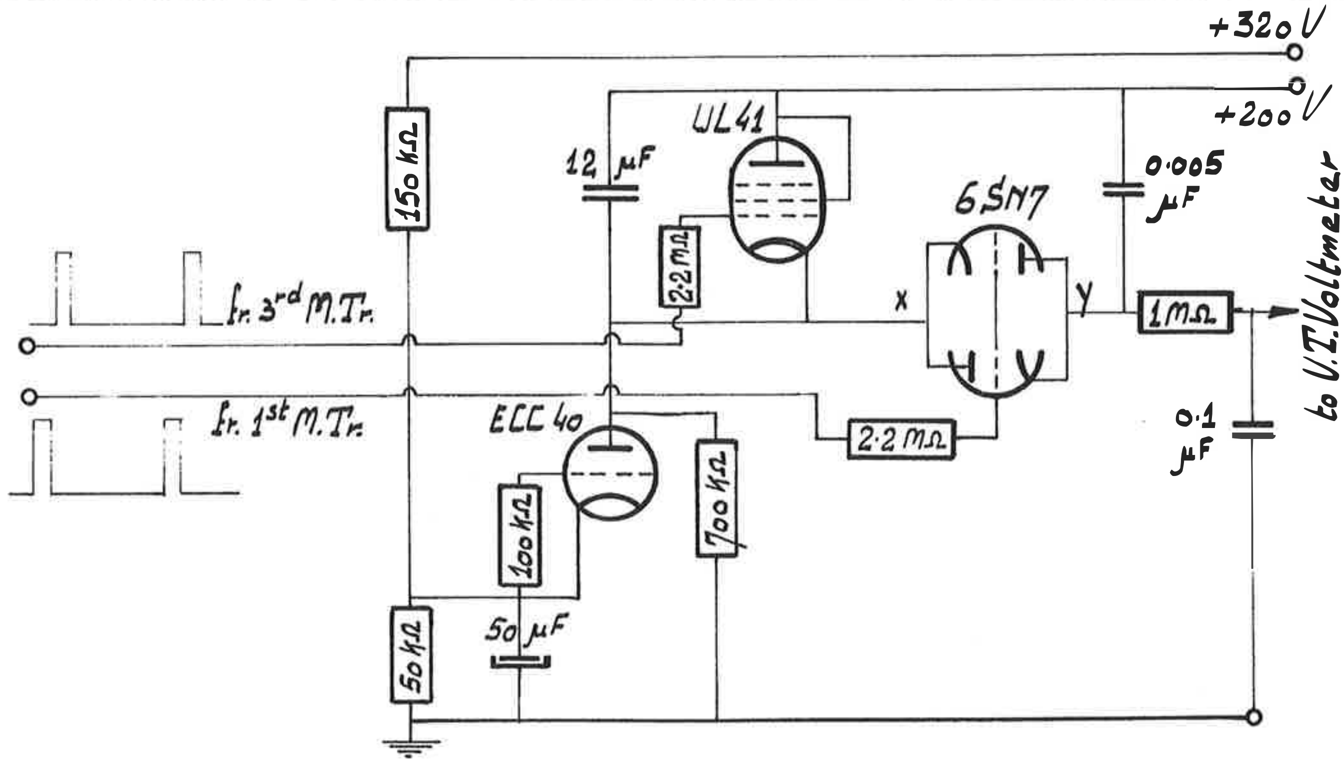
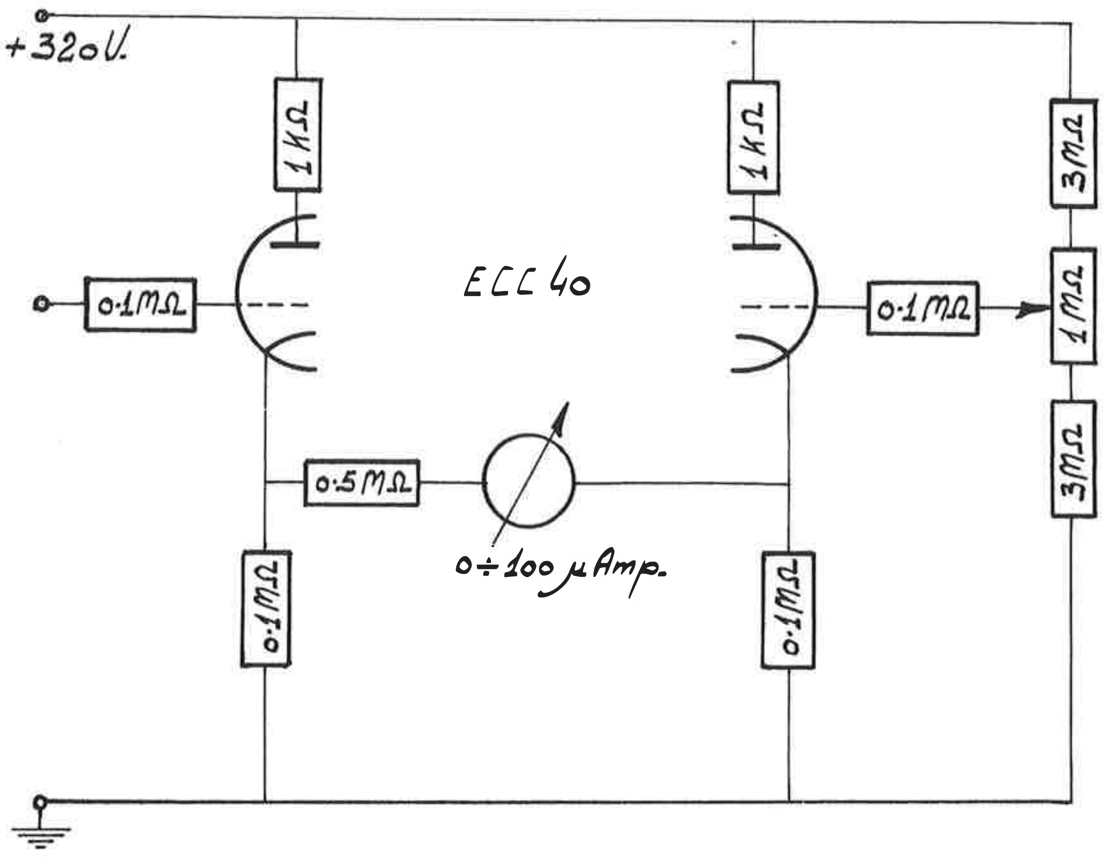


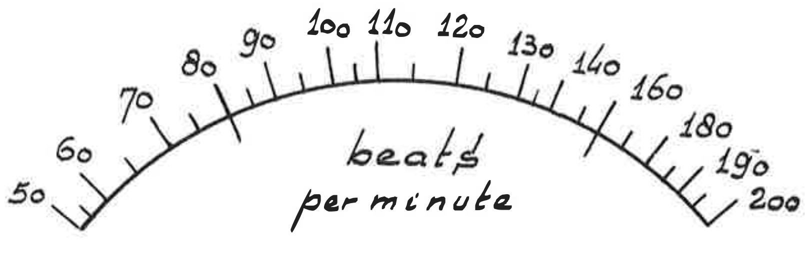
Diagram of Charging Circuit and Electronic Relay.

Fig. 12



Vacuum tube volt meter.

Fig. 13



Scale division.

Fig. 14

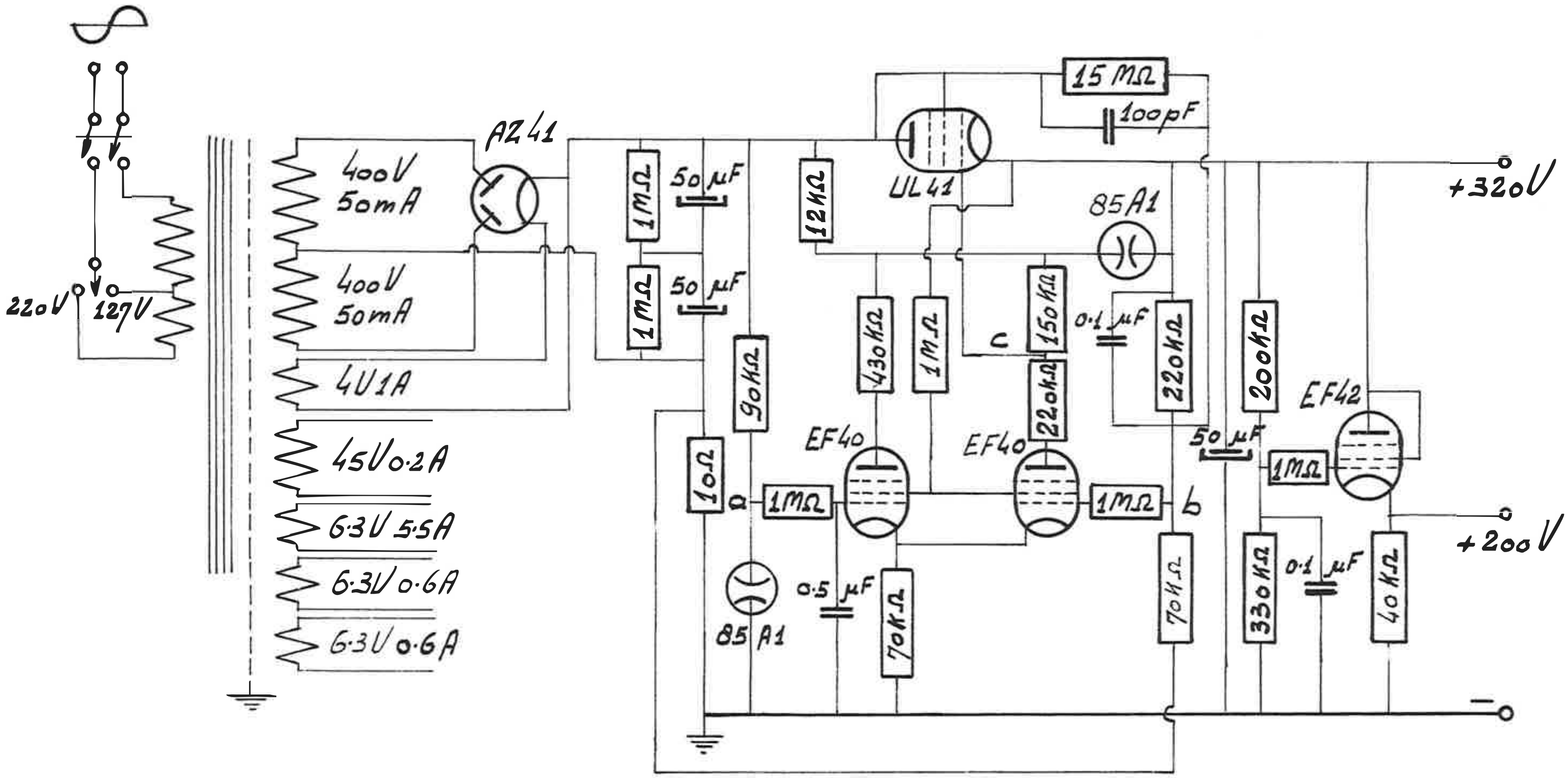
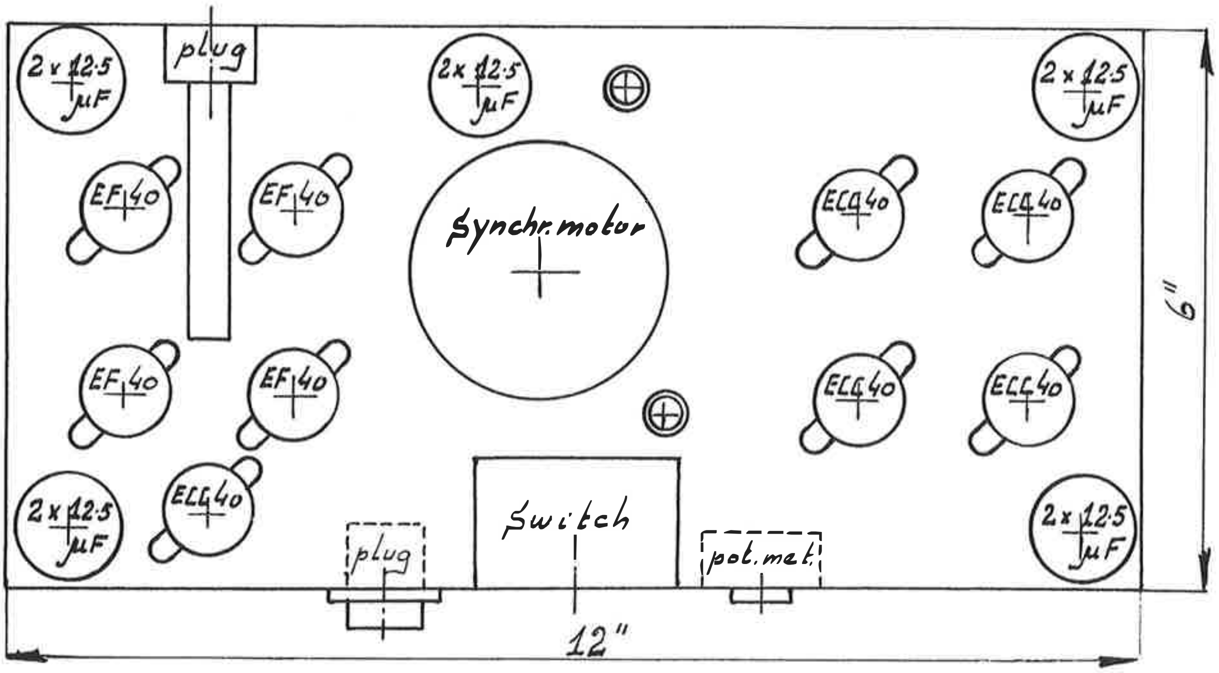


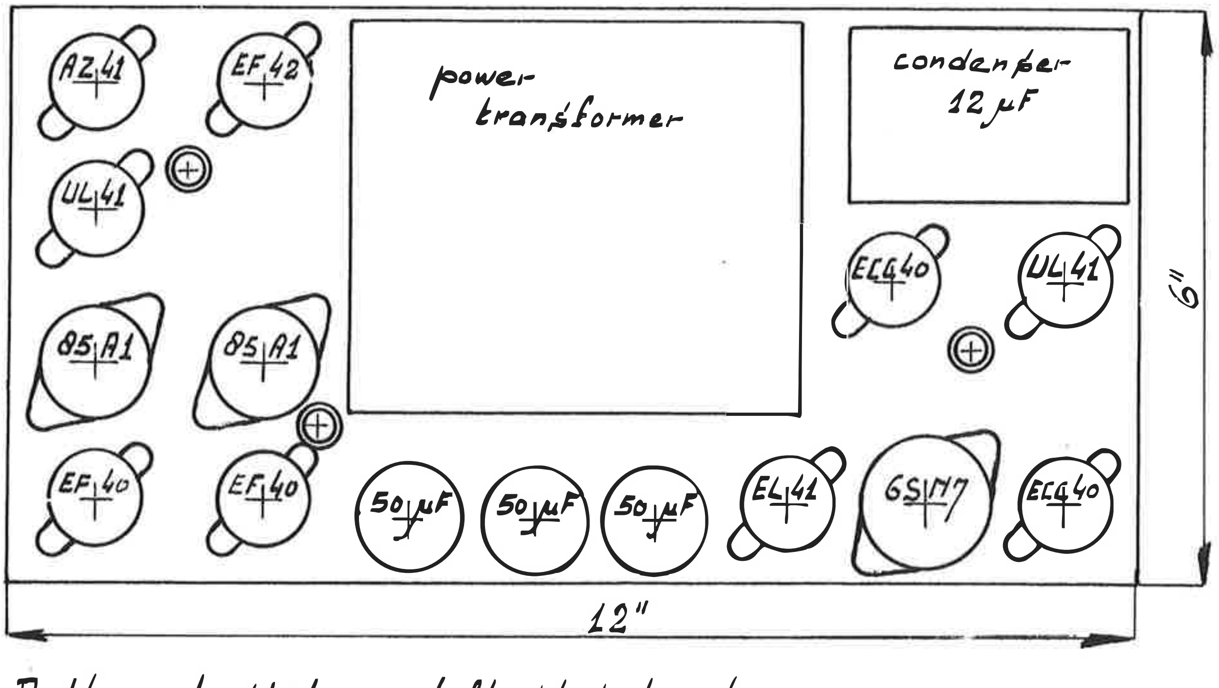
Diagram of Power Supply and Stabilization.

Fig. 15



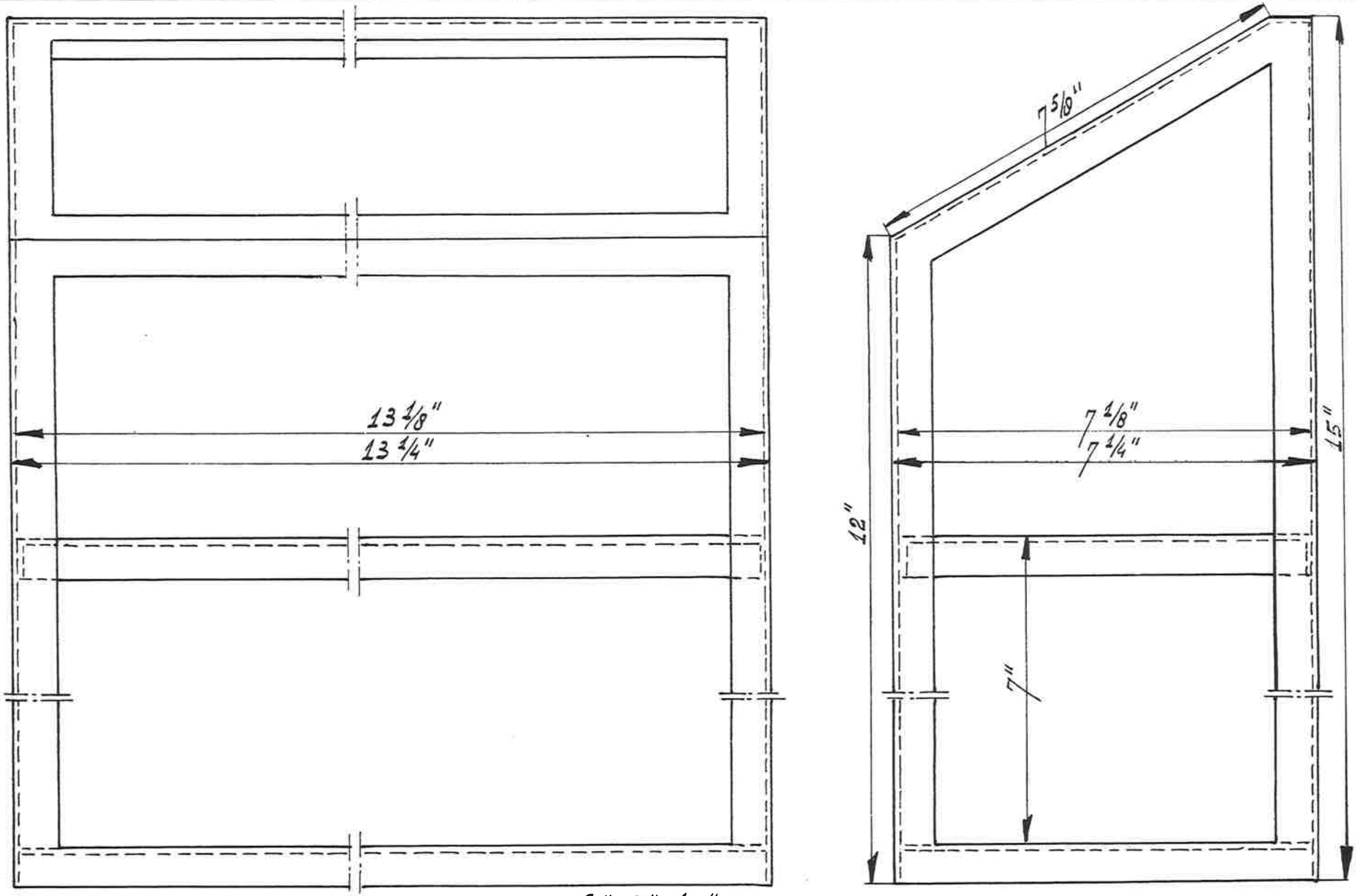
Top chassis. left: amplifier. right: triggers.

Fig. 16



Bottom chassis. left: stabilization.
right: generator, electronic relay and vacuum tube volt meter.

Fig. 17



Frame. Scale 1:2. Angle iron 5/8" x 5/8" x 1/16"

Fig. 18

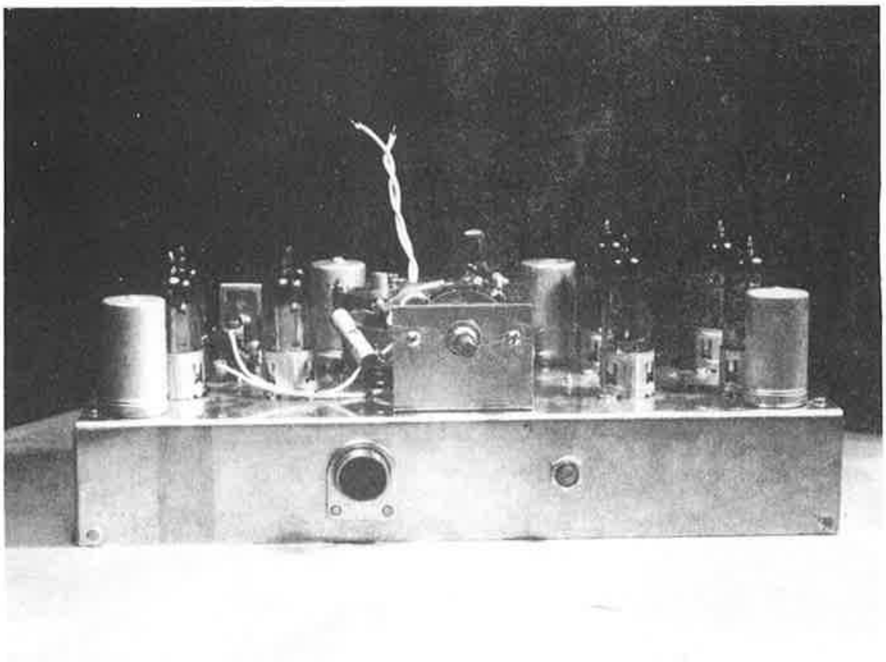


fig. 19 Foto eerste chassis
fig. 19 Picture of top chassis

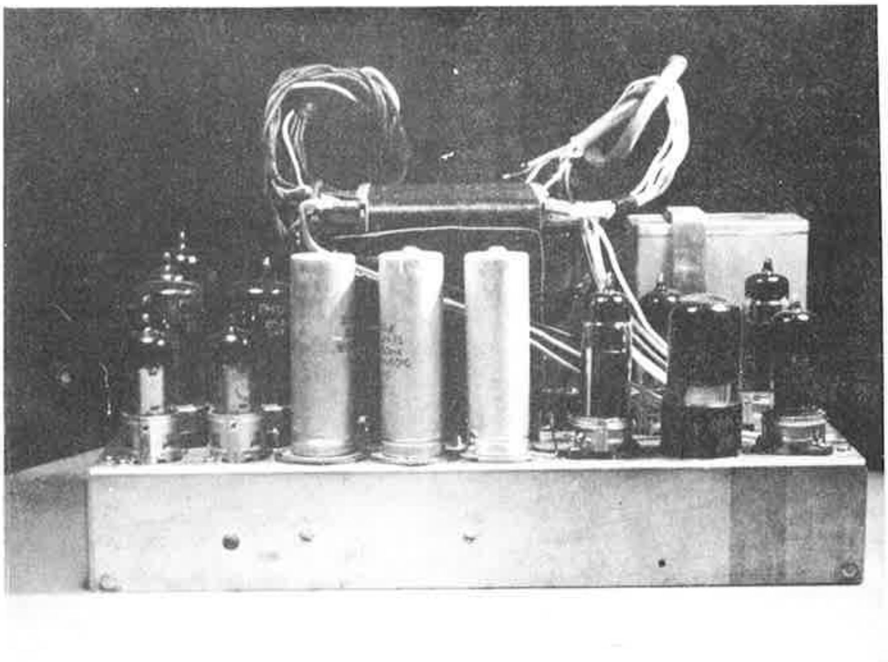
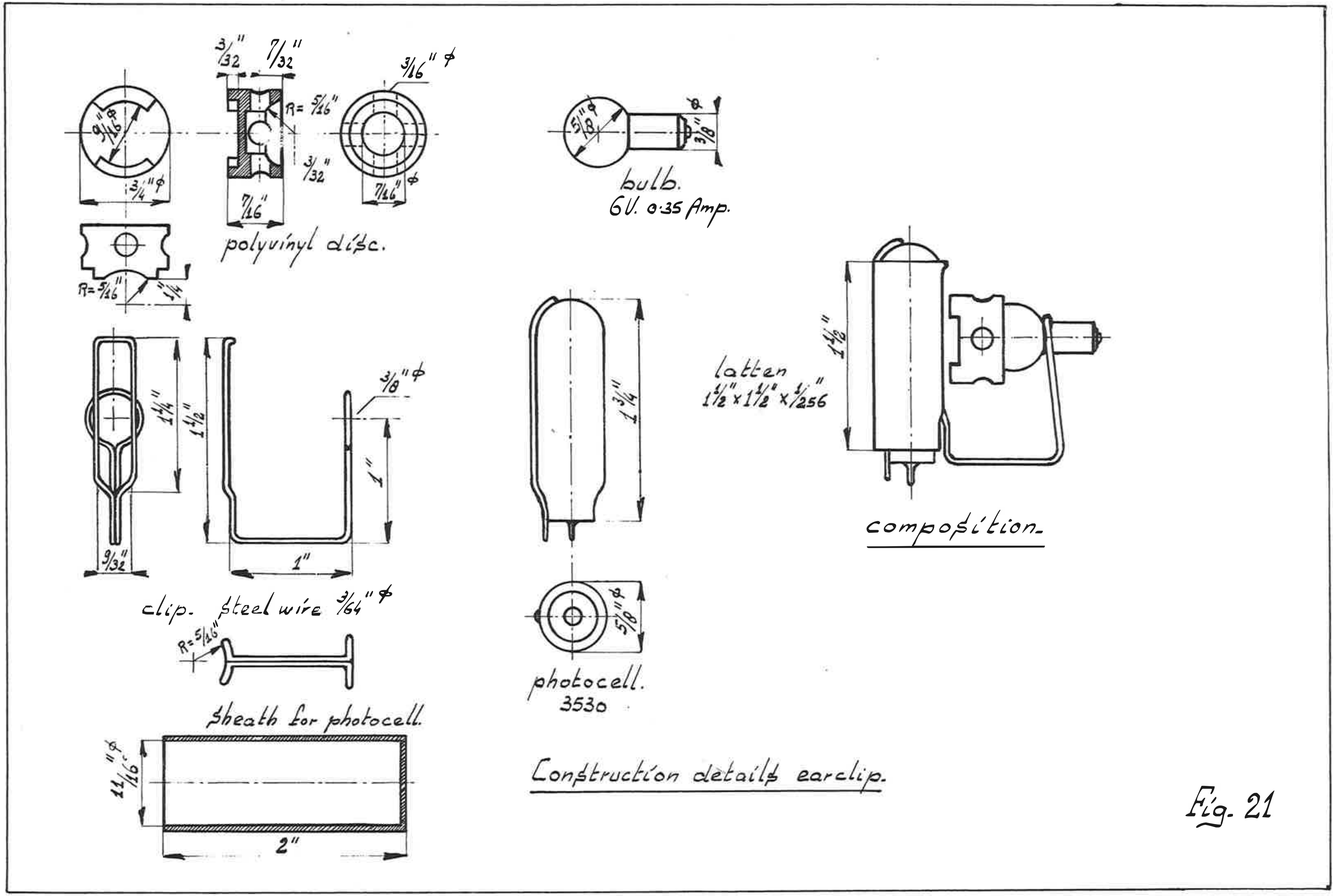


fig. 20 Foto tweede chassis
fig. 20 Picture of bottom chassis



Construction details earclip.

Fig. 21

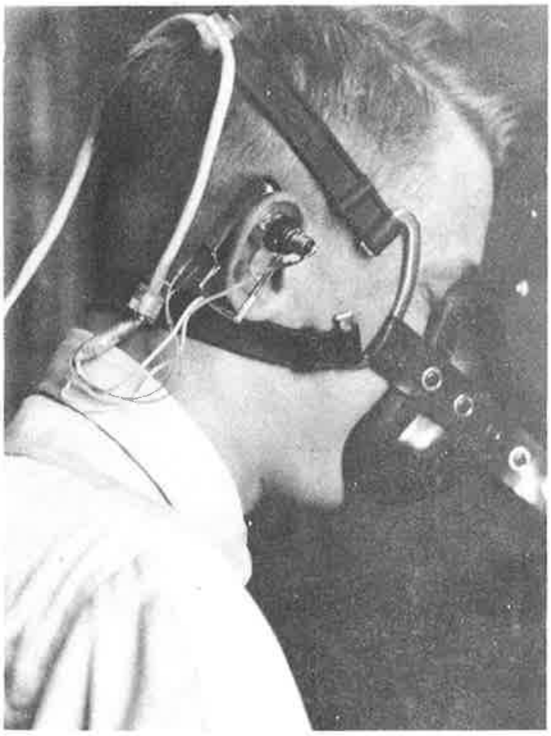


fig.22 Foto bevestiging van de oorklem
fig. 22 Picture of earclip in situ

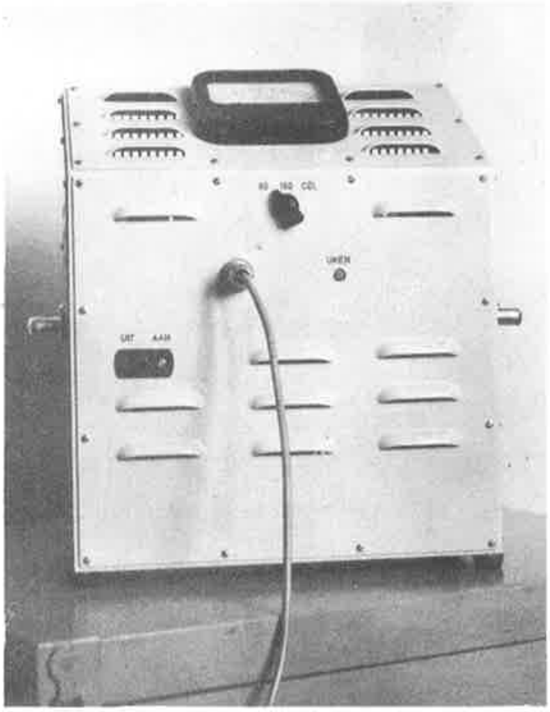


fig. 23 Foto van het complete toestel
fig. 23 Picture of the complete instrument

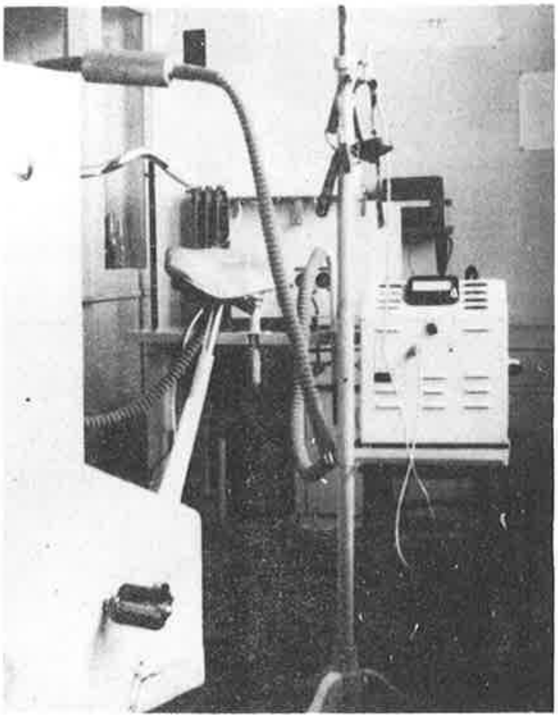


fig. 24 Foto van een meetopstelling
fig. 24 Picture of a complete arrangement