

**THE MEASUREMENT OF MUSCLE STRENGTH
IN ALLERGIC RESPONSE**

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My grateful thanks also to Dr. Rosemary Baker for her help with the statistical results.

ABSTRACT

The purpose of this thesis was to show a relationship between muscle strength and allergic reactions. Clinics have for many years relied on what have become traditional methods for testing for allergic reactions. These include such tests as the Patch test and the Skin-Prick test. Both these tests cause discomfort and irritation to sensitive patients.

The historical development of allergies is outlined, showing that scientists and clinicians in the late 18th and early 19th century were aware of certain reactions which people showed to apparently normal non-reactive foods. The development of methods of diagnosing allergies such as the elimination diet, which dates back to approx 1940, are surveyed. Current practices are also studied with the use of photographs. The reaction of the skin to modern day testing practices is shown. In some cases these reactions are quite violent.

The Applied Kinesiology Test is examined as a universally used test which when carried out by an experienced Kinesiologist can give a true but highly subjective response to a patients allergic condition.

A system has been developed based on the relationship between muscle strength and allergies, the components of this system were readily available at

little cost. Once a basic system was built it was possible to perform trials on patients at an established allergy clinic.

With the aid of a data printer it became possible to prove first graphically and second statistically that there was a statistically valid relationship between the measured muscle strength and allergies.

The conclusion shows that the final version of the operating system is capable of equaling the performance of an experienced Kinesiologist, showing its results both digitally and graphically rather than subjectively.

The various deductions and recommendations which are detailed, point towards a readily marketable device which could represent a potential break through in modern allergy testing. The system will also open the way for clinicians to make an objective assessment of the relationship between muscle strength and allergic sensitivity via further research.

CHAPTER 1

CHAPTER 1

As a background for later work it was necessary to study the history of allergies, how long allergies have existed and where the term allergy came from. This chapter will deal with all the above problems and also explain how the splits in the definitions of allergy have come about.

Historical Background

Allergies were described in the First Century B.C. when Lucretius expressed that:

(1)

"Quod ali cibus est aliis fuat acre venenum."
 "What is food to one may be fierce poison to others!"

In the early seventeenth century, Beaumont and Fletcher echoed a rather similar thought:

(2)

"What one man's poison, signor, is another's meat and drink."

Samuel Pepys made this entry in his diary on September 5, 1664:

(3)

"Came W. Bowyer to dine with us, but strange was it to see he could not endure onyons in sauce to lamb, but was

¹- Roods H.A: Letter Lancet 1841;2:717-718

²- Alvarex W.C: Food sensitivity and conditions that may be confused with it. Med.Clin.North Am. 1929;12:1589-1602(May)

overcome by the sight of it, so was forced to make his dinner from an egg or two."

It was not until the nineteenth century that physicians began to pay serious attention to what was then called 'food idiosyncrasy'. One of the early reports on the role of foods in asthma appeared in The Lancet. It was worthy of noting that the author, H.A.Roods, believed asthma attacks to be mediated through the vagus (pneumogastric) nerve, a view that is now standard:

(1)

"In a case of a gentleman who has for many years been subject to attacks of spasmodic asthma of a very severe character and for whom I have long been in the habit of prescribing, the attack appeared to have been the result of, and occasioned by errors in diet, if he partook freely of either veal, salted meat, pastry or other edibles, an embarrassment of the respiratory functions to a greater or less degree, usually supervened about half an hour or an hour afterwards; and though many of these slight attacks passed off quickly, yet they frequently increased in intensity and terminated in extremely violent paroxysms of spasmodic asthma. The inference drawn from these facts is that the paroxysms alluded to result from a morbid impression made on the gastric branches of the pneumogastric nerve, which impairment was conveyed through the trunk and pulmonary branches of this nerve to the mucous membranes of the air passages, where it produced some function derangement, the effects of which were the phenomena constituting the malady in question."

In 1855 there appeared a detailed account of a man whose asthma and constitutional symptoms were caused by wheat. This report is remarkable for being one of the pioneer observations of what is now called food allergy, but also that the author brings out four points now known to be important:

⁽¹⁾
1- Roods H.A: Letter Lancet 1841;2:717-718

1. Food allergy tends to cause a tremendous increase in mucous secretions.
2. In severe cases, the odour of the offending food may cause symptoms.
3. Food allergy may begin immediately after birth, even after the first feeding.
4. Many people ignore the patient's insistence that he cannot eat a given food, not believing in his infirmity.

This report was presented by Overyton and appeared in the Southern Journal of Medical and Physical Sciences, Vol.3, 1855:

(1)

"The patient has throughout his life, from his cradle to his grave, been the victim of what is possibly a unique idiosyncrasy of constitution. In his own words he declared: 'of two equal parts tartar and wheat flour I would rather swallow the tartar than the wheat flour.' If he ate flour in any form or however combined, in the smallest quantity, in the two minutes or less he would have painful itching over the whole body, accompanied by severe colic and tormina in the bowels, great sickness in the stomach and continued vomiting, which he declared was ten times more distressing than a tartar emetic. About ten minutes after eating the flour the itching would be greatly intensified about the head, face and eyes, but tormenting all parts of the body and not to be appeased. These symptoms continued for two days with intolerable violence, declined on the third day and ceased on the tenth. In convalescence the lungs were affected and in expectoration he raised great quantities of phlegm, and really resembled a phthisical patient. At this time he was confined to his room, with a great sickness, similar to that of a person recovering from an asthmatic attack. The mere smell of wheat produced symptoms in a minor degree, and for this reason could not, without suffering, go into a mill or house where the smallest quantity of wheat flour was kept. His

condition was the same from the earliest times and was laid when an infant at the breast after being fed 'pap' thickened with wheat flour. One of his female neighbours, not believing in his infirmity but considering it only a whim, put a small quantity of flour in the soup which she gave him to eat at her table, stating that it contained no flour, and as a consequence of the deception he was bedridden for ten days with his usual symptoms."

From these two reports both appearing well over a century ago, it was obvious that food allergy, whatever it was called, has long been recognised. At the close of the nineteenth century and at the beginning of the twentieth, a number of observers began to correlate clinical experience with laboratory findings to show that what had been called 'idiosyncrasy' was an immunological phenomenon. It was interesting that as early as 1855, Bulkley had pointed out that urticaras, eczema and asthma had a common origin. He credited Sir Andrew Clark with suggesting this five years earlier. Bulkley also made significant comment that these diseases:

(1)

"May result from some altered condition of the blood."

The term allergy was introduced by a Viennese Doctor, Baron Clemens Von Pirquet in 1906, to mean 'altered reactivity'. Von Pirquet was a paediatrician and felt the need for a new medical term to describe certain reactions in his patients. These changed reactions included the development of immunity to infection, on the one hand, and marked reaction to certain foods, pollen on the other. He attributed altered reactivity caused by the allergen to the

1- Bulkley L.D: Asthma as related to diseases of the skin
Br. Med. J. 1885;2:954-956

absence of antibodies in the immune system. In 1905 an Australian physician wrote a massive two volume work on the food factor in disease. In it he detailed numerous cases in which common ailments, including apparent 'mental' problems were caused by eating certain foods.

In 1912 a New York paediatrician had diagnosed an allergy to eggs in a child, the first time in modern medicine that a common food had been linked specifically to allergy.

In the 1920's Albert Rowe published his first observations on how to eliminate suspected foods from the diet in order to detect allergies in them. In 1925 experiments had shown that many adverse reactions to pollen or food could be transferred from one person to another by injecting a small amount of blood serum under the skin. The area around the injection site became very sensitive to the allergen. This and other evidence pointed to the immune system. Most of those working in the field decided to limit the definition of allergy to where the immune system was demonstrated to be involved.

After 1925, allergies were defined in terms of reactions between antigens and antibodies in the body, similar to the reactions which occur in some infections.

This new definition made the field of allergy admirably 'scientific' in the narrow sense, since antibodies could be measured with ever increasing precision. This ruled out

many bizarre and puzzling reactions which formerly had been a valid subject for inquiry. From this point forward, allergists were divided into two camps, the orthodox who accepted the antigen-antibody definition and worked within its boundaries, and the unorthodox who continued to investigate reactions in which such immunological reactions could not necessarily be demonstrated. One prominent scientist, Dr Arthur F. Coca of Cornell University who was considered the Dean of American Immunologists raised his voice to complain about the restrictions of the field.

The investigations of the food allergists, the unorthodox ones, became a kind of undercurrent in the profession, a heresy that was tolerated so long as it was kept in check. Complicated political and economic factors also came into play which were beyond the control of any of the participants in this drama.

Orthodox allergists focused their attention on pollen, dust, moulds and danders, which can produce dramatic and measurable reactions in sensitive individuals. However pollens and dust are politically innocuous; one can criticise them as much as one likes, with few repercussions. Food, especially common foodstuffs such as corn wheat, milk, eggs etc, could not be criticised quite so easily as powerful financial interests were concerned.

In 1949, Dr T.G.Randolph obtained an appointment to testify at the Food and Drug Administration Boards hearing

in Washington. Dr. Randolph requested that food ingredients especially corn, cane and beet sugars be listed on the labels of processed food products. After the testimony he was no longer allowed to mention school affiliation in his articles and was soon deprived of his position at the North Western Medical School.

In 1951, he made what was probably his most important discovery; he came to the conclusion that man's increasing pollution of the environment with chemicals was a major source of chronic illness. By this he did not simply mean reactions to toxic chemicals, such as those which formed the 'killer smog' which killed hundreds in England during the 40's. Randolph discovered the non-toxic chemicals that were used in the home and place of work were giving rise to headaches, depression and multiple muscle and joint aches and pains.

In the 1960's the results of painstaking research work by a Japanese husband and wife team Kinoshige and Tezuko Ishizaka working in the United States, were that they discovered the type of antibody now known as IgE, which can be quantitatively specific to an allergen.

In 1965, Dr. Randolph and four of his colleagues founded the Society for Clinical Ecology. In 1970 it was reported by Kailin and Hastings that a patient who was subject to migraine and who contracted mumps thereafter had evidence of electromyographic weakness in the left quadriceps muscle when challenged with a known allergen;

egg. In 1976 Miller had modified the intradermal skin-testing food allergy. Studies in 1977 by Miller and in 1978 by Rapp which were double blind tests showed that this type of therapy works satisfactorily in food allergy.

In 1978 at a meeting of the Clinical Ecology Society Dr Rapp of Buffalo showed a film of a little girl who went into a catatonic state when she was given, as a test, scollops. The girl did not know when she was receiving the scollops or another type of food, that is to say she was not aware of when she was eating the scollops. In 1980 Dr Jean Monro showed that provided that the results of a RAST test (see chapter 3, section 2.3) are interpreted as an individual profile of a specific IgE, rather than an average score, the results can be helpful in indicating food allergy. Later in 1982, Dr Monro reviewed the association of allergy and migraine headache. In all 17 studies were reported involving more than 1236 patients.

Research has been carried out over the past years to find the relationship between allergies and sinutenses (migraine, asthma, etc.) affecting the human body and also to find the reason for the allergic reaction. As such this thesis will try to find a relationship between allergies and muscle strength.

CHAPTER 2

CURRENT ALLERGY TESTING PRACTICES

To determine the possibility of an allergic nature in a clinical condition, the use of various diagnostic procedures to reveal a specific allergic reaction are employed.

Taking a history of allergy includes a general medical history. In addition, however, a special allergy history helps to disclose the factors that produce the patient's symptoms. This history forms one of the most useful parts of an allergic investigation and in experienced hands, frequently supplies clues of prime importance in the solution of the patient's problem. To arrive at the history of the patient a complete analysis must be made including height, weight, sex, age, mode of onset of the first attack, time of onset (day or night), duration, severity, frequency, family history, social history, past medical history. These are then followed by laboratory examination, a urine sample, blood count to determine the presence of anaemia, examination of the nose throat and sinuses to eliminate the possibilities of infection.

Dermatological examination is needed to see if there is any question of a different diagnosis of dermatitis that may or may not be due to allergy and is also needed to determine what type of allergen the patient should be tested for.

Using the above information the patient can be tested by using one of many methods of allergy tests such as

skin-prick tests; the RadioAllergoSorbentTest (RAST), patch test are all available to the clinician. There is also a test based upon muscle strength used by Applied Kinesiologists. All the above tests are described in the following section, the muscle strength test being the particular concern of this thesis.

2.1 The Skin Prick Test

This test is usually less important than an established history of the patient, however it can provide useful confirmatory evidence of a reaction to certain allergens. The skin prick test is very simple to carry out but does not give absolute evidence of clinically relevant allergy. That is to say in the case of respiratory tract symptoms provoked by pollen, house dust, mite excreta or animal dander, there is a 75% agreement between the results of provocation tests and skin tests. The concordance between skin prick test results and symptoms from ingested allergens is much lower. Skin prick testing is only of limited help in the diagnosis of food allergic disease.

2.1.1. Method of Skin Prick Test

The skin is cleaned, prick sites are marked and a small drop of each allergen solution is placed on the skin. A lance is introduced through the drop of solution to a depth of about 1mm into the skin and then pulled out raising the skin in the process, see figure 1. The skin should not bleed, the site is then blotted dry. Because of the risk

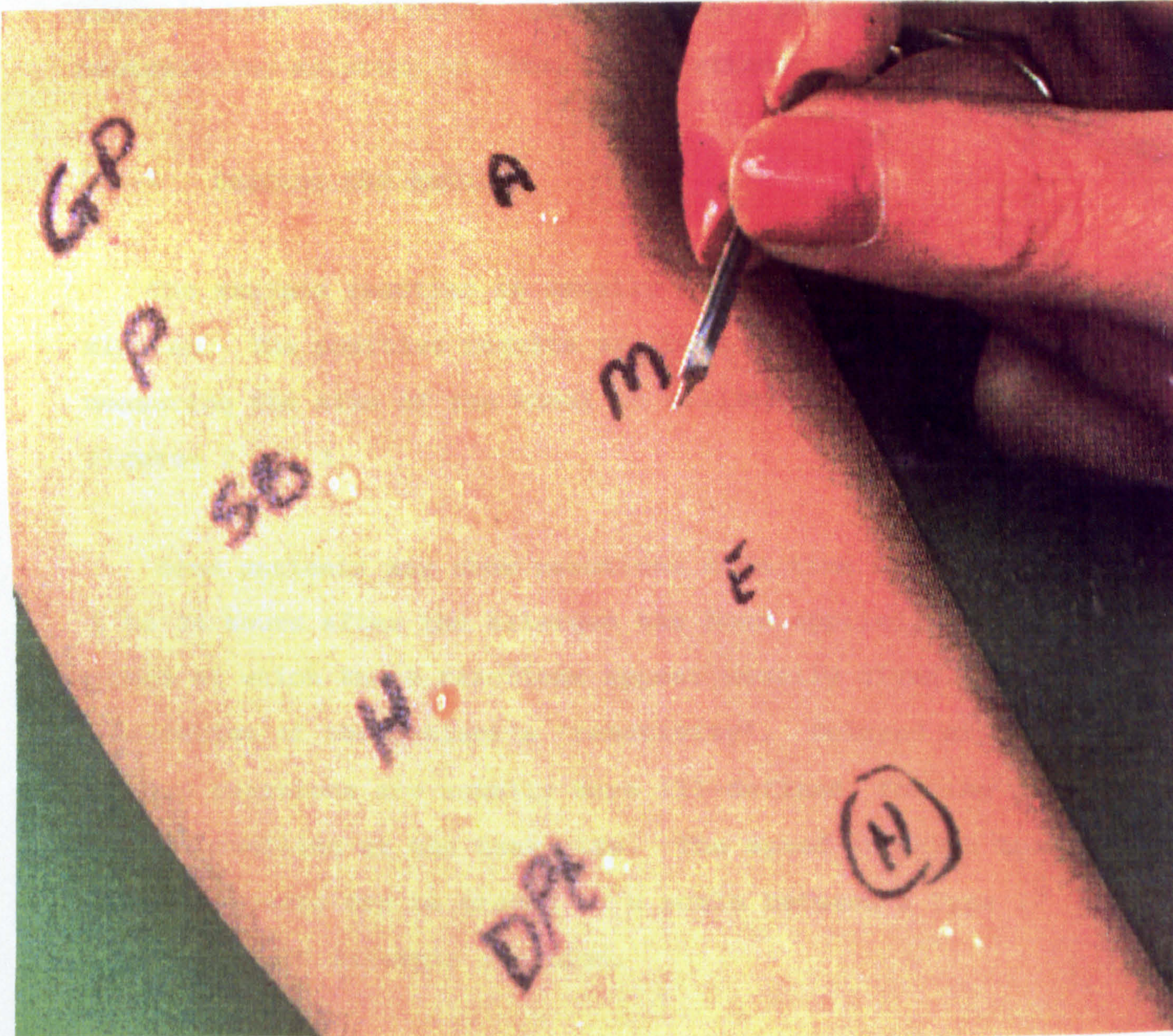


Figure 1 The Skin Prick Test

from: William F. J., Rino C: A Colour Atlas of
Allergy,
Wolf Medical Publications Ltd., London, 1988

of anaphylactic reaction it is essential that a medically qualified person is immediately available together with a 1/1000 adrenalin solution, antihistamines and other resuscitation facilities such as the patients own neutralising solution or intravenous vitamin C and oxygen.

2.1.2 Reading the Results

The maximum reaction is usually seen after 15 - 20 minutes. The positive results are best recorded by measuring the size of the wheal in millimetres. See figures 2 and 3.

Some patients may show reactions some time later, from 1 to 24 hours after the allergen has been applied. The speed at which these reactions appear usually gives an indication of the patient's 'reactivity'. Delayed or masked reactions are usually more ill-defined, forming only a soft swelling at the test site. The speed at which the patient reacts can be graded on a scale between a Type I and a Type IV Allergic reaction.



Figure 2 Measuring The Size of the Wheal at the Test Site

from: William F. J., Rino C: A Colour Atlas of Allergy, Wolf Medical Publications Ltd., London, 1988



Figure 3 Multiple-Positive Skin Prick Test Result

from: William F. J., Rino C: A Colour Atlas of Allergy, Wolf Medical Publications Ltd., London, 1988

2.2 Patch Tests

Patch Tests are principally used to identify causative allergens in suspected allergic contact dermatitis. It is considered that they should not be used on patients with acute eczema as results are often misleading.

The allergens are formulated in appropriate concentrations and then placed in shallow aluminium wells of about 1cm^2 , these are called Finn chambers. See figure 4.

2.2.1 Method

The Finn Chambers are applied in strips to the patients back and kept in place with hypo-allergenic tape. See figure 5. The skin is marked appropriately and the patient is asked to keep the area dry. The patches are removed after 48 hours and the skin examined for any positive response. See figures 6 and 7. A positive response is normally characterised by itching and erythematous swelling often accompanied by vesiculation, all of which may extend beyond the margin of the patch in positive results of a very strong nature.

This reaction represents the cell-mediated delayed hyper-sensitivity, (Type IV response). Irritants may also cause a similar response, but the reaction is commonly painful rather than itchy and epidermal necrosis may occur.

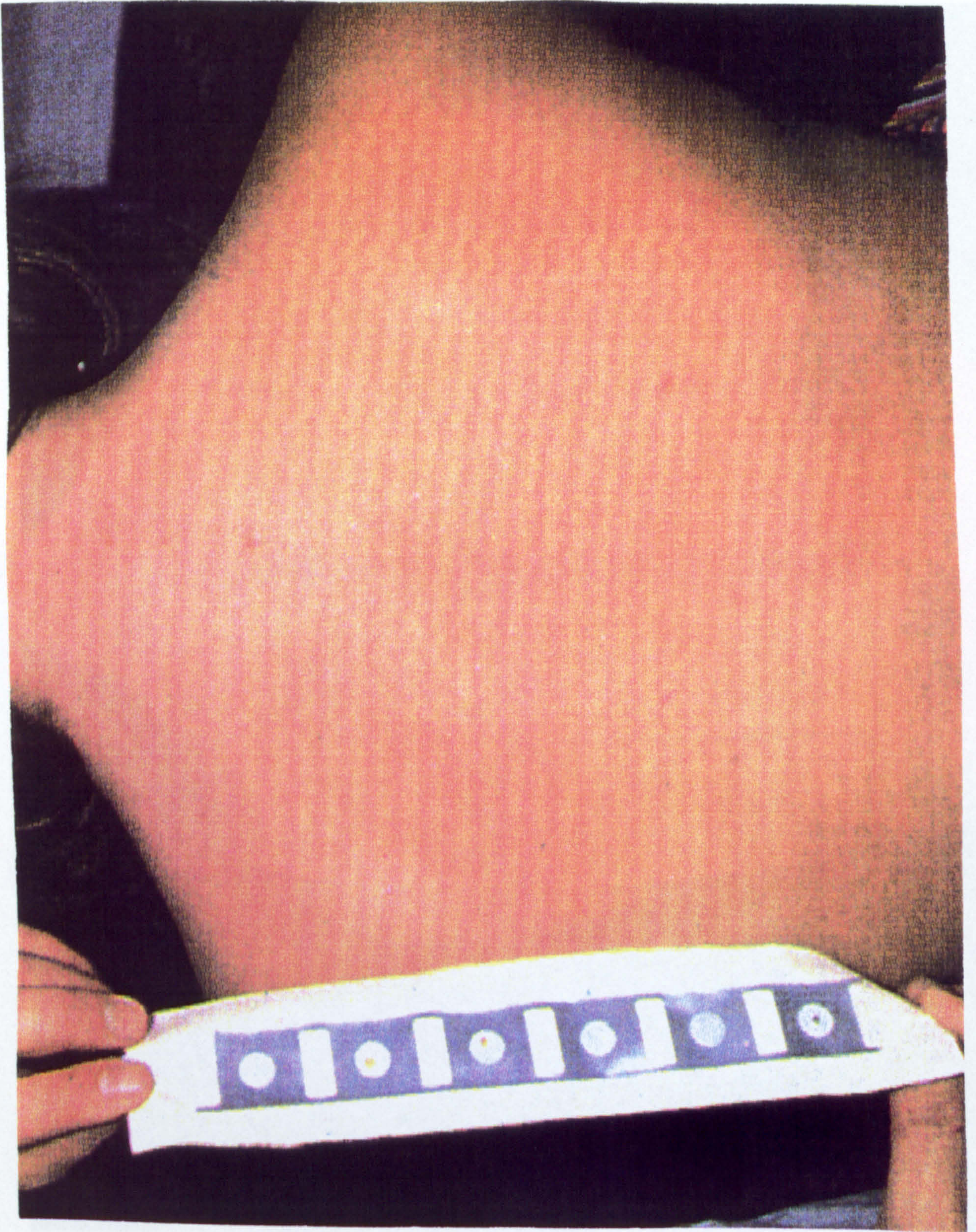


Figure 4 Allergens in 'Finn' Chambers about to be applied to subject's back.

from: William F. J., Rino C: A Colour Atlas of Allergy, Wolf Medical Publications Ltd., London, 1988

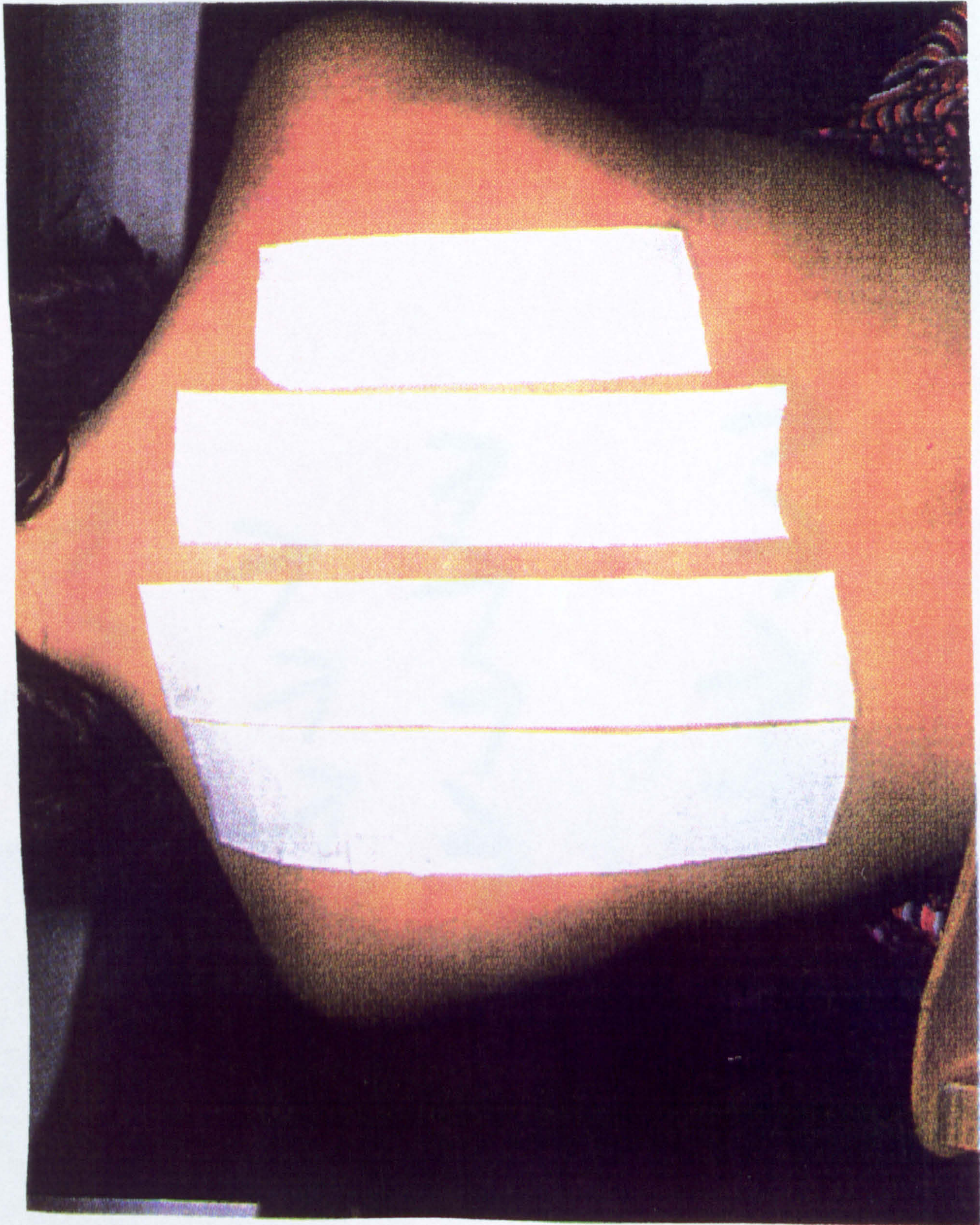


Figure 5 Allergens applied to subject's back with hypo-allergenic tape.

from: William F. J., Rino C: A Colour Atlas of Allergy, Wolf Medical Publications Ltd., London, 1988

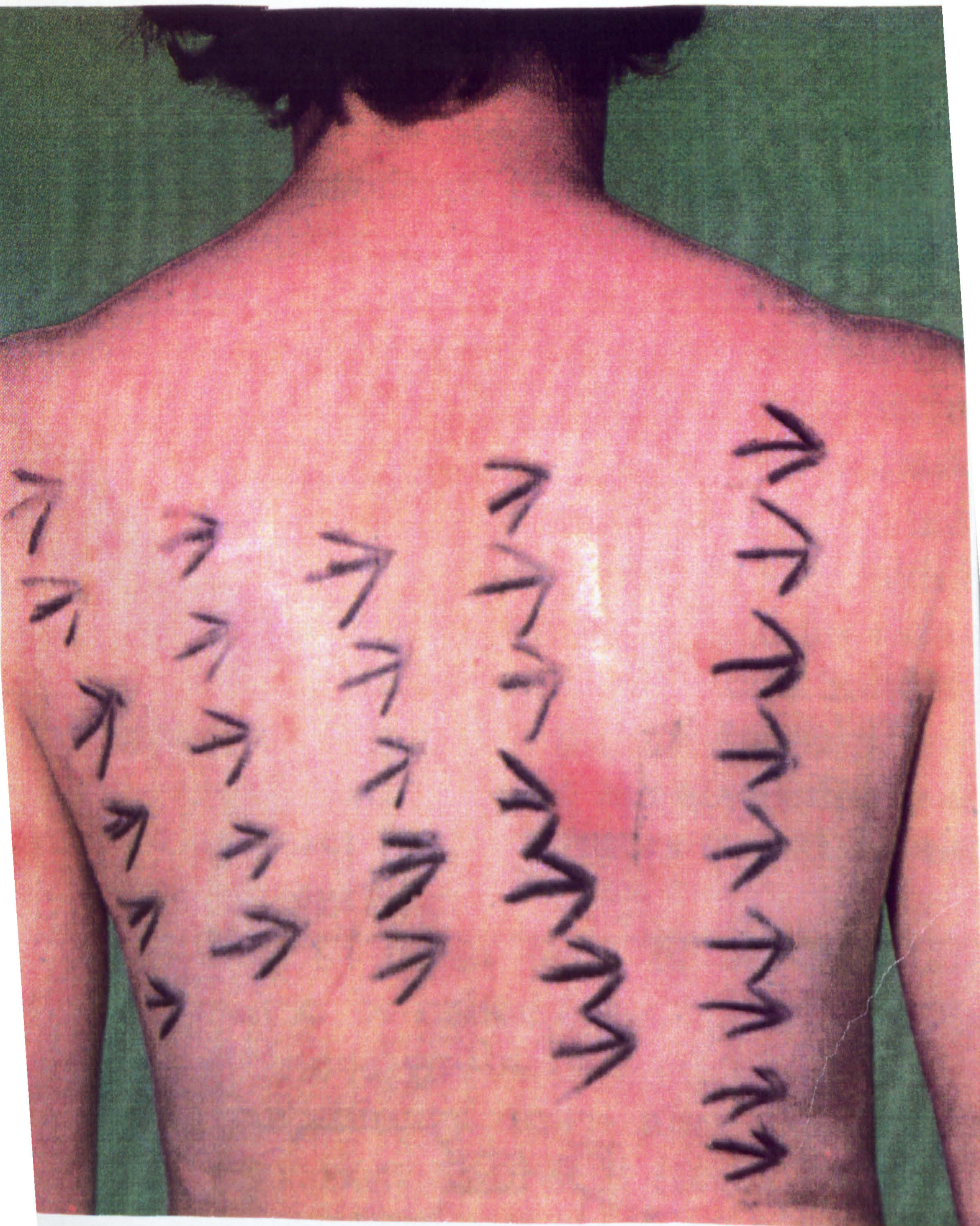


Figure 6 Multiple Positive Result on Subject's Back

from: William F. J., Rino C: A Colour Atlas of Allergy,
Wolf Medical Publications Ltd., London, 1988



Figure 7 Close up of Positive Result

from: William F. J., Rino C: A Colour Atlas of Allergy, Wolf Medical Publications Ltd., London, 1988

With most substances the allergic response reaches its maximum at 48 hours, however some substances may take up to 96 hours to respond. Patch testing is simple and clinically useful, but the results are not always easy to interpret. The concentration and presentation of the allergen is critical and distinction between an allergic reaction and an irritant response is not always clear.

2.3 RadioAllergoSorbent Test (RAST)

The RAST test measures the level of IgE antibody that a person has to a specific substance such as a food, a protein or a pollen. There are four stages to the test as follows:

2.3.1. Method

1. An extract of the food (or other potential allergen) is applied to beads of a substance called seraphose. This is an inert substance that simply acts as a surface on which reactions between the allergen and antibody can take place. The food molecules remain attached to the seraphose beads throughout the test.

2. A sample of the patient's serum (the liquid part of the blood) is allowed to flow over the beads. If the blood contains IgE antibodies to that food, these will bind to the food allergen. The seraphose beads, which are on a disc, are then rinsed to remove everything that is not already bound to the beads, that is to say, only the IgE molecules should remain.

3. Another liquid is then poured over the beads. This contains a special type of antibody called anti-IgE, which binds specifically to the stem of IgE molecules. If there is IgE attached to the beads, then the anti-IgE will bond on to them. If no IgE is present, then all the anti-IgE will be washed away.

4. The anti-IgE was previously marked with a radioactive marker or coloured marker. This means that the amount of IgE present can be ascertained by measuring the radioactivity or colour given off by the beads. The amount of anti-IgE present is a measurement of how much IgE (specifically for the food or substance tested) is present in the patient's blood. This is known as the RAST score.

In general, the RAST test produces results comparable with the skin prick test in (Type 1) allergic disorders.

2.4 The Scratch Test

This test is similar to the skin-prick test but it differs by using a needle that has had the eye-end filed. The needle-end is stuck into a cork which is, in turn, placed into the top of a bottle that contains the allergen which is to be tested. The filed-end of the needle is then rotated to make a scratch on the surface of the skin. It gives similar results to skin-prick testing and is safer when used on children and infants. However, the method is imprecise and not usually that helpful.

2.5 Applied Kinesiology

This technique was used by applied kinesiologists for testing allergies. One such doctor is Dr R Choy. He is a medical practitioner who graduated from Australia. He has an allergy clinic in Middlesex, where I met him some two years ago when I was introduced by my supervisor.

2.5.1. Method

In this test demonstrated to the writer, the doctor stood directly in front of the patient, with the patient extending the dominating arm to shoulder height. The doctor then placed one hand on the patients shoulder and the other on the patients extended wrist, see Figure 8.

The doctor tested the resistance of the arm to see how much pressure the patient could resist without the arm dropping. This was to give the doctor an idea of how much pressure the patient would give as a natural response without the introduction of an allergen. An allergen was then introduced to the patient's free hand and was then held by the side. Pressure was then applied to the other arm and the doctor was able to tell how much pressure was required from the tests performed prior to the introduction of an allergen. The response to the pressure applied by the kinesiologist from the patient could be interpreted in two ways. If the patient's elevated arm remained outstretched whilst under pressure then they were considered not to be allergic to that respective allergen. However if the arm lowered under pressure then they were considered to be allergic to that respective allergen.

The tests that were carried out in the presence of the writer were double-blind tests. That is to say that neither the patient nor the clinician testing the patient knew what allergens the patient was being tested with, nor did the patient. Nor did the clinician know whether the patient was already allergic to a given substance.

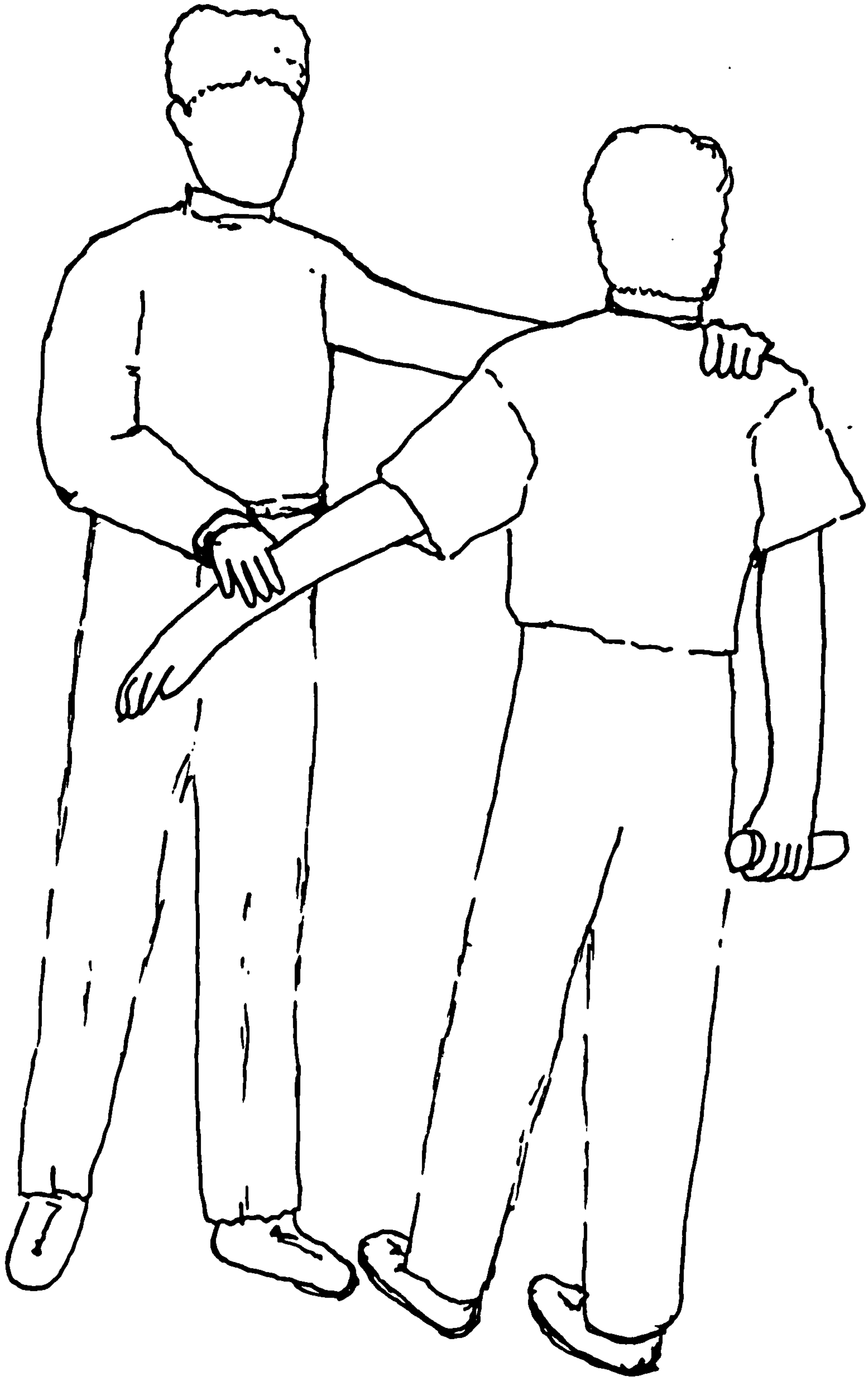


Figure 8 An illustration showing and Applied Kinesiologist testing a patient for an allergic reaction

He performed a set of tests on both a father and son. When the two sets of tests were performed and the results compared with a skin-prick test and a RAST test performed earlier, the results of the kinesiological test were the same as the established and accepted RAST and Skin-prick tests.

The only minus point to the applied kinesiological test is that it takes a great deal of experience to know how much pressure to apply to the wrist of the patient, without affecting the results.

CHAPTER 3

THE THEORY OF THE INSTRUMENTATION OF THE ALLERGY TESTING SYSTEM

The historical importance of electronics in medicine and the history of control systems are discussed in this chapter. The theory of the instrumentation of the allergy testing system, the formulas used and where they originate from are also discussed in this chapter.

3.1 History of Electronics in Medicine

It was recognised soon after the Second World War that electronic techniques were beginning to play an increasingly important role in medical research and practise. The physician now finds electronic instruments all around him in the hospital or in his office. The use of computers has also invaded the practice of medicine, and instrumentation is deeply rooted in the scientific research as well as clinical medicine.

Medical education and training enables physicians and nurses to make better evaluation of patients' information. With more advanced instruments they can make more accurate diagnoses far more quickly.

Medical Instrumentation has not only revolutionised hospital "labs" but also intensive care and coronary care units to the point that at almost every corner of today's

rapidly expanding health-care centres some form of electronic instrument can be found.

At present we can monitor physiological data, compile it and use it in making a diagnosis. However in the future, with the current development of electronic instrumentation, and the ease of access that the physician will have to it, we can now see that it is possible that physiological and electrical activity will become an automatic extension of the nervous system, with the results being interpreted virtually instantaneously.

3.2 History of Control Systems

The control system is that means by which any quantity of interest in a machine, mechanism or other equipment is maintained or altered in accordance with a desired manner.

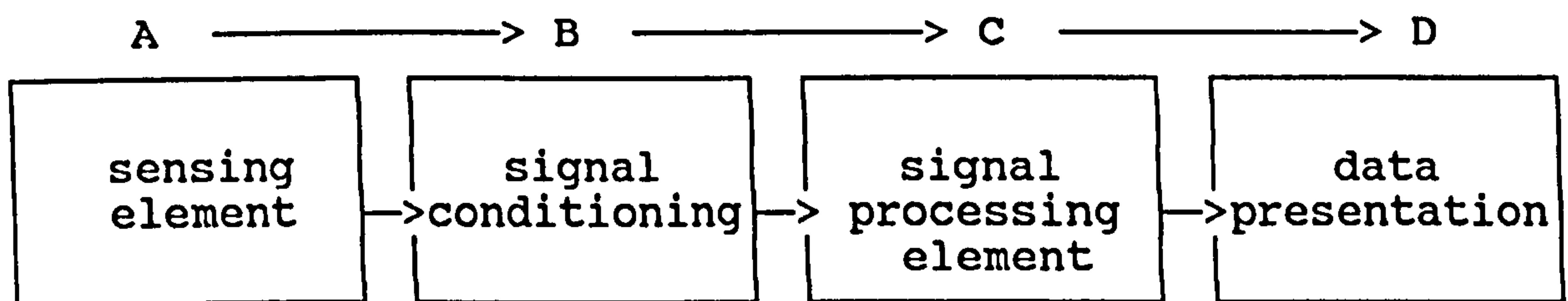
Automatic control systems did not appear until the middle of the 18th century. The first automatic control (The Fly-Ball Governor) to control the speed of steam engines was invented by James Watt in 1770. Control engineering has enjoyed tremendous growth during the years since 1955, particularly with the analogue and digital computers and with the perfection achieved in the computer fields.

A control system is a collection of physical objects connected together to service an objective. No physical system can be represented in its full physical intricacies

and therefore idealizing assumptions are always made for the purpose of analysis and synthesis of systems. A physical system can be modelled once a physical model of the physical system is obtained, the next step is to obtain a mathematical model which is the mathematical representation of the physical model through the use of appropriate physical laws. When the mathematical model of a physical system is solved for various input conditions the result represents the dynamic response of the system.

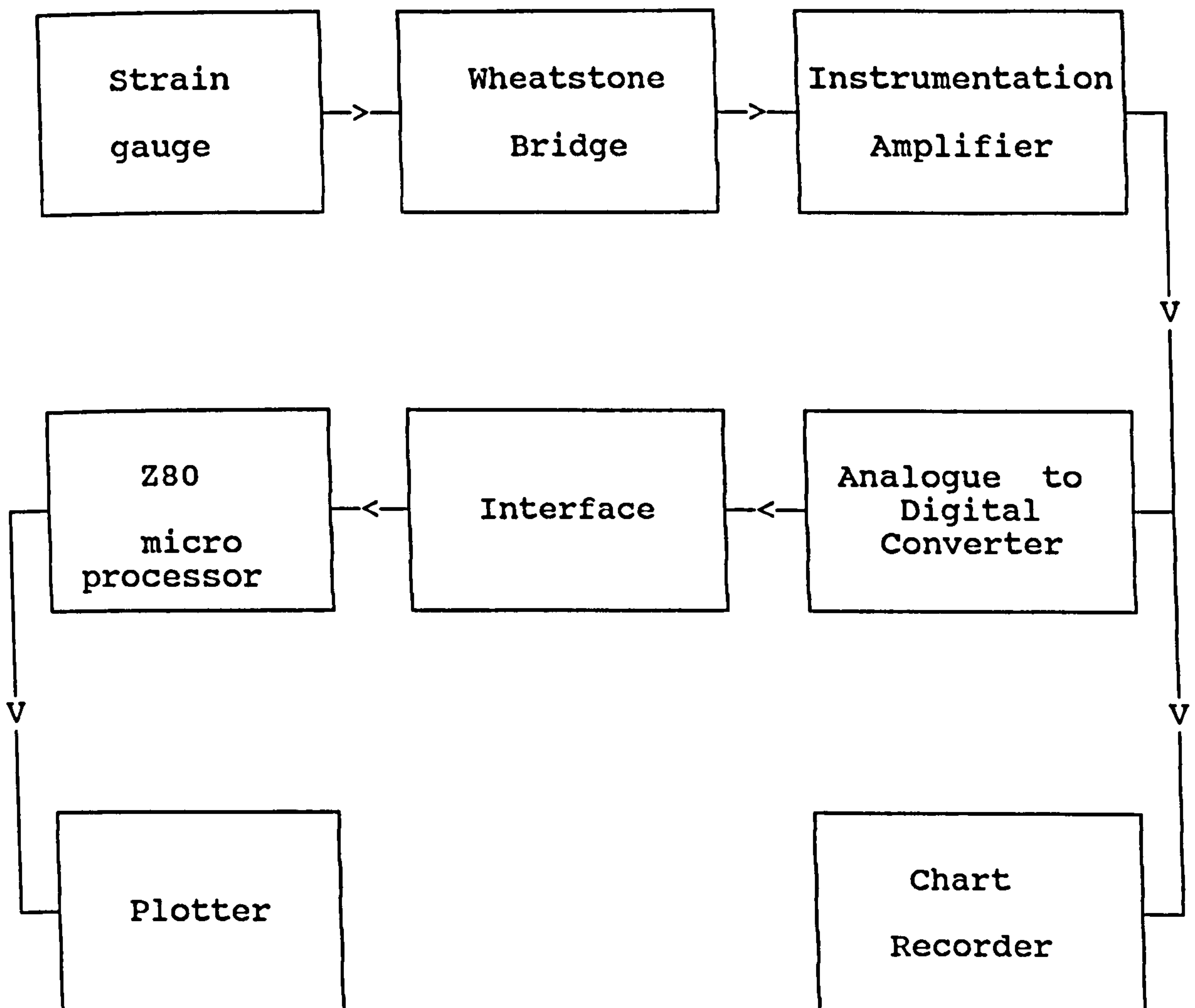
3.3 The Theory of the Instrumentation of the Allergy Testing System

To design and build a system that can measure muscle strength and hence detect allergic reaction, the design project should start with a flow diagram representing the stages of the process. Below, the flow diagram outlines the four basic stages required.



A. Sensing Element This is an element which is in direct contact with the system. In this particular case a 'strain gauge' was employed. Sensing elements depend on some physical law which can be expressed mathematically.

- B. Signal Conditioning Element At this stage of the process the signal conditioning element takes the output from the sensing element and converts it into a form suitable for further processing.
- C. Signal Processing Element This changes the numerical value of the signal but does not alter the physical nature of the variable.
- D. Data Presentation This is the final stage where a physical output can be seen by means of a printer, plotter or digital display. The next stage is to convert a flow diagram into an instrumentation diagram. The processes shown in this diagram show the conversion of mechanical energy into an electrical signal.

Instrumentation Flow Diagram

3.4 Strain Gauge

One device which engineers employ to obtain information about the size and the distribution of strain in structures such as buildings, bridges, aircraft etc. is the electrical strain gauge. This converts mechanical stress into a resistance change in itself by using the fact that the resistance of the wire depends on its length and cross-sectional area and this is changed by mechanical stress.

One type of gauge consists of a very fine wire (this is an alloy containing mostly nickel, iron and chromium) cemented to a thin piece of paper or plastic as shown in figure 9. In use, it is securely attached with a very strong adhesive to the component under test so that it experiences the same strain as the component. If for example an increase of length strain occurs, the wire will consequently get longer and thinner and on both accounts the resistance increases. Thick leads connect the gauge to a resistance measuring circuit such as a Wheatstone bridge.

3.4.1 Resistance Strain Gauge

Consider a conductor of uniform cross-section with an area (A) and length (L), made of a material with a resistivity (ρ). The resistance (R) of such a conductor is given by the following equation:

$$R = \frac{\rho L}{A} \dots\dots\dots (1)$$

If this conductor is stretched or compressed its resistance will change due to dimensional change, (length and cross-sectional area), and because of a fundamental property of the material called piezo-resistance, which represents a dependence of resistivity (ρ) on the mechanical strain. To find how a change of dR in R depends on the basic parameters, we differentiate equation (1):

$$dR = \frac{A(\rho dL + L d\rho) - \rho L dA}{A^2} \dots\dots\dots(2)$$

Since Volume (V) = AL

$$dV = AdL + LdA$$

also:

$$dV = L(1 + \epsilon) A (1 - \nu \epsilon)^2 - AL \dots\dots\dots(3)$$

where $\epsilon \triangleq$ unit strain and $\nu \triangleq$ Poisson's ratio

Since ϵ is small $(1 - \nu \epsilon)^2 \approx 1 - 2\nu \epsilon$

then:

$$dV = AL\epsilon (1 - 2\nu) = AdL + LdA \dots\dots\dots(4)$$

and since $\epsilon \triangleq \frac{dL}{L}$

$$AdL (1 - 2\nu) = AdL + LdA \dots\dots\dots(5)$$

$$-2A\nu dL = LdA \dots\dots\dots(6)$$

substituting equation (2)

$$dR = \frac{\rho AdL + LA d\rho + 2\nu \rho AdL}{A^2} \dots\dots\dots(7)$$

and thus:

$$dR = \frac{\rho dL (1 + 2\nu)}{A^2} + \frac{L d\rho}{A} \dots\dots\dots(8)$$

dividing by equation (2)

$$\frac{dR}{R} = \frac{dL}{L} (1 + 2\nu) + \frac{d\rho}{\rho} \dots\dots\dots(9)$$

and finally:

$$\text{gauge factor } \frac{dR/R}{dL/L} = \overset{(\#1)}{1} + \overset{(\#2)}{2} + \overset{(\#3)}{\frac{d\rho/\rho}{dL/L}} \dots\dots(10)$$

where:

#1 = resistance change due to length change

#2 = resistance change due to area change

#3 = resistance change due to piezo resistance being affected.

Thus if the gauge factor is known, a measurement of dR/R allows measurement of the strain

$$\frac{dL}{L} = \epsilon$$

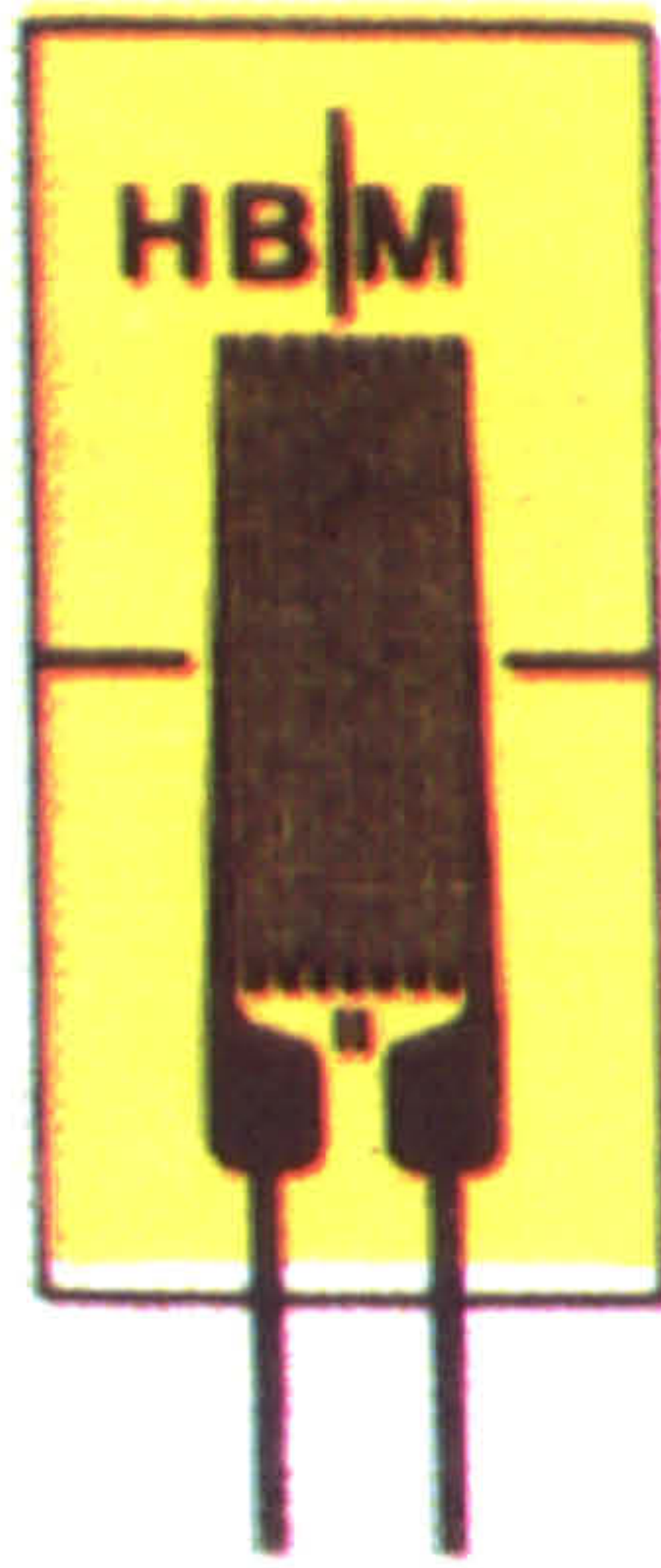
3.5 Adhesive for Strain Gauge

Rapid adhesive Z 70, made by HBM of Oxford, was developed to apply strain gauges of the bonded resistance type. It was excellent adhesive because of its fast room-temperature cure and ease of application when properly handled. (See Table 1)

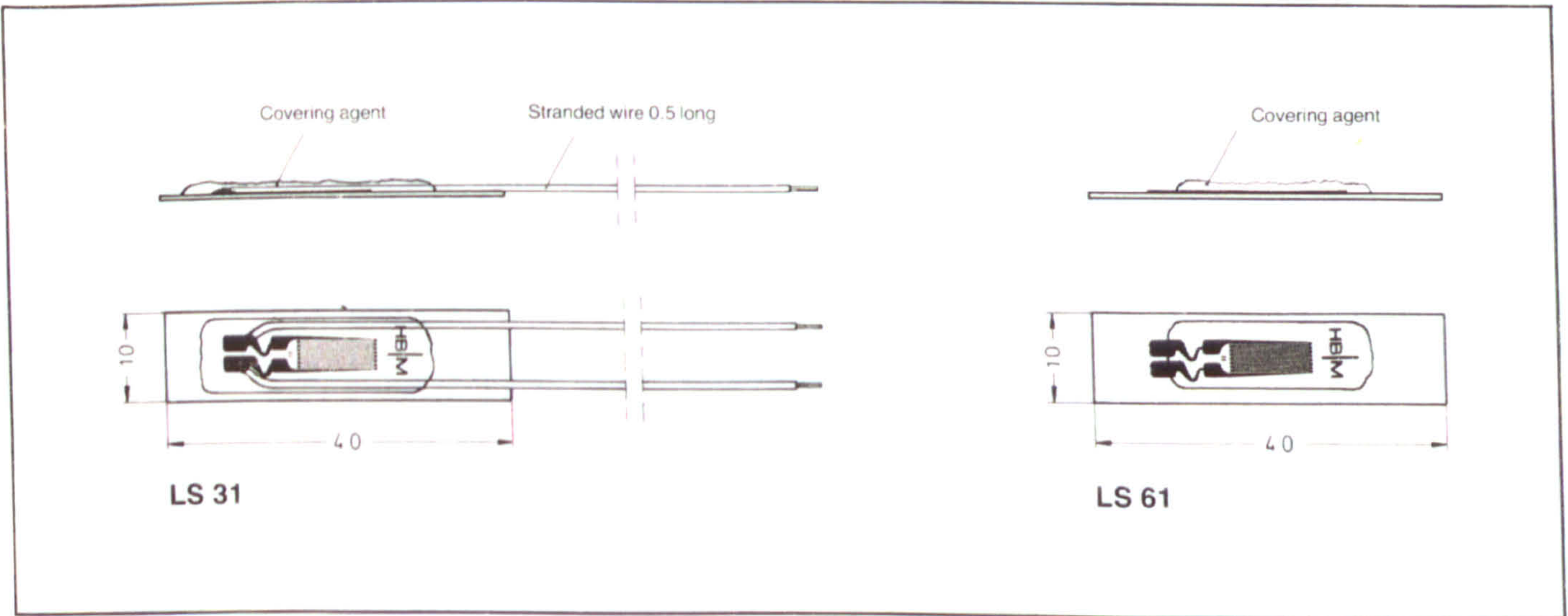
The adhesive is compatible with all HBM strain gauges. It should be applied between the temperatures of + 70° to + 80°F (approx + 20° to + 30°C) and in a relative humidity environment of between 30% to 65%.

Subject	Setting time (seconds)
Steel	40 - 80
Aluminium	30 - 60
Plastics	30 - 60

Table 1 Shows time for Z70 to set for different materials



A



B

Figure 9

A HBM Strain Gauge

B HBM Strain Gauge Schematic Diagram

3.6 Preparation of Surface

The object of the following preparation work is to create a surface smooth enough for the adhesive to adhere to properly. The steps are as follows:

1. Course Cleaning. Any rust, scale paint and other such 'contamination' must be removed from the area.
2. Smoothing Down. Any scratches on the surface should be smoothed down with emery paper to ensure good adhesion.
3. Degreasing. The gauging area must be then degreased with a solvent (in this case Freon TF). This degreasing must be done with an uncontaminated solvent, thus a one-way container was used. The solvent is then applied to a gauze sponge and then the surface is wiped clean.
4. Surface Roughening. A slightly roughened surface provides a better anchor for the adhesive. This is produced by using a slightly rougher grade of emery paper than before.
5. Fine Cleaning. All dust and dirt from the roughening process has to be removed with Freon TF on a number of gauze sponges, continuously wiped until no discolouration occurs. The surface is

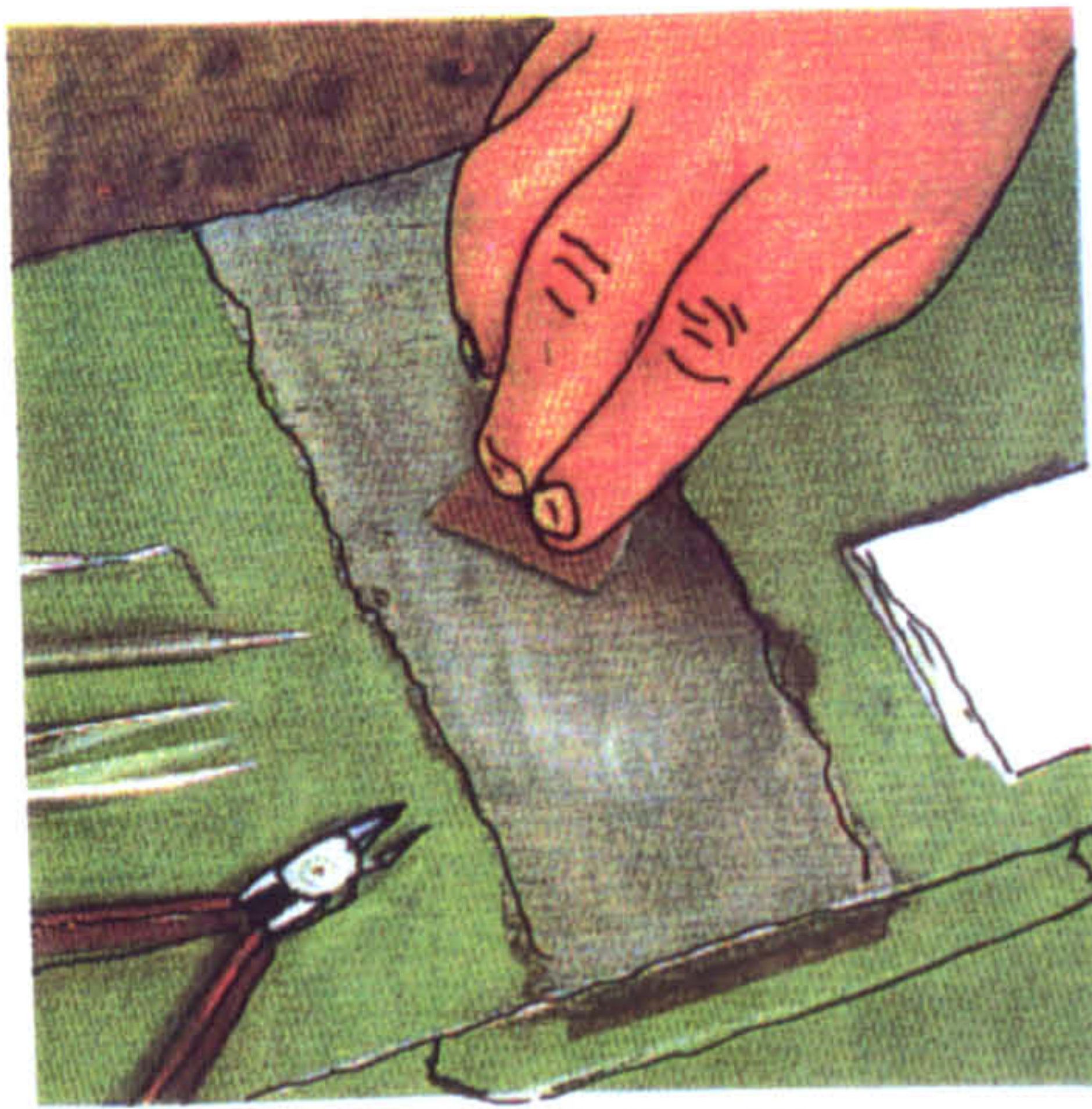
then washed with water and allowed to dry.

6. Preparation of the Strain Gauge. The bonding side of the strain gauge is carefully cleaned with a swab soaked in Freon TF. The residual moisture is dried using a hot air blower.

7. Adhesive. The strain gauge and the surface to which it is to be applied is now ready to be adhered together. The adhesive (Z 70) is very fast drying so the process of connecting the strain gauge to the surface where it is required must be done quickly. Two or three drops of the adhesive are applied to the surface of the measuring area and then spread out. The strain gauge is then applied to this surface and a piece of adhesive tape placed on the top to keep it in place whilst the adhesive cures. Incidentally, the tape used cannot bond to the surface of the measuring area. After pressing on the area for a few seconds the tape is then removed.

8. Connection to the Strain Gauge Two thick wires are then connected to the strain gauge leads, which are then in turn connected to the rest of the circuit.

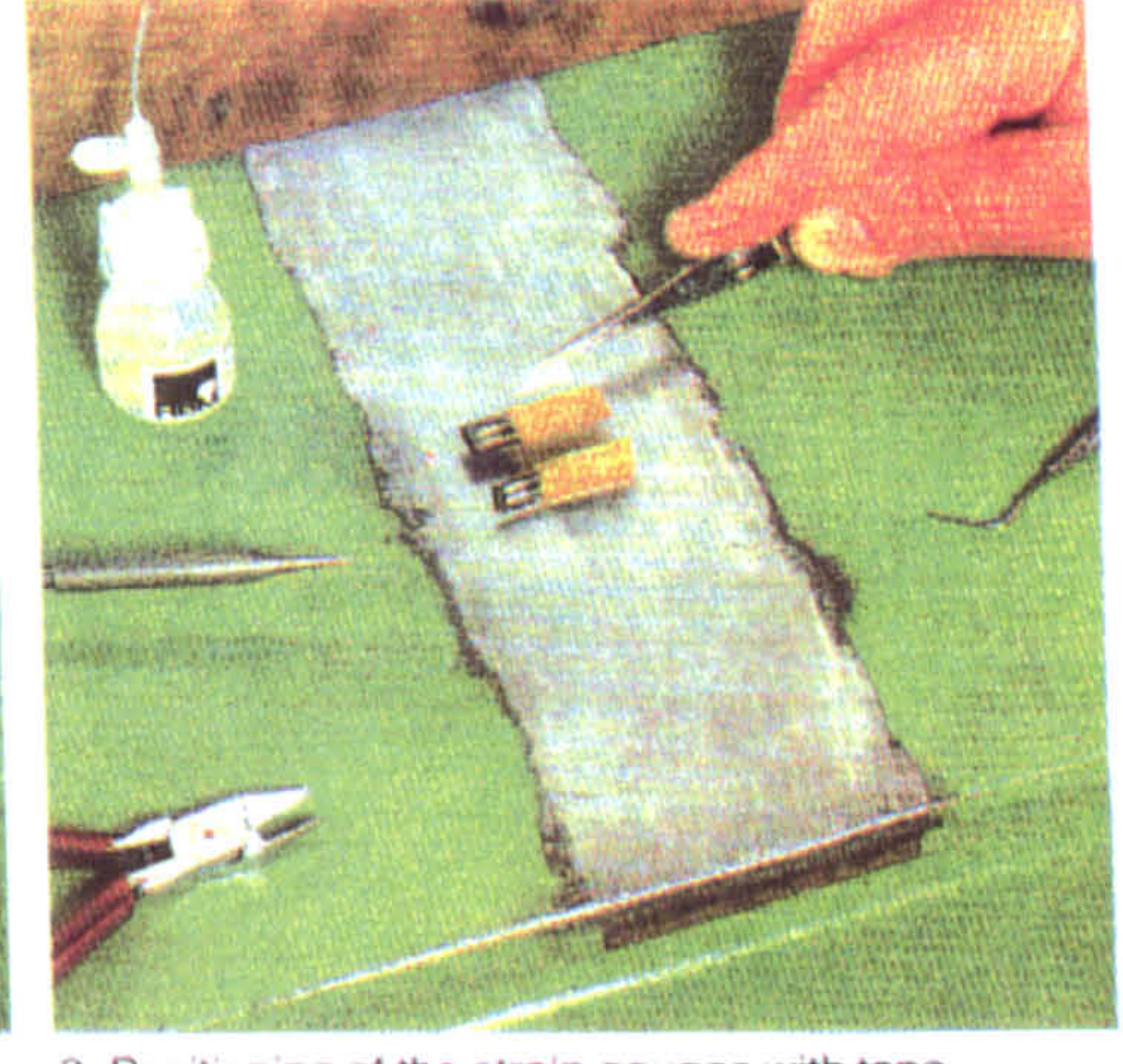
The following diagrams show pictorially the process that has been described:



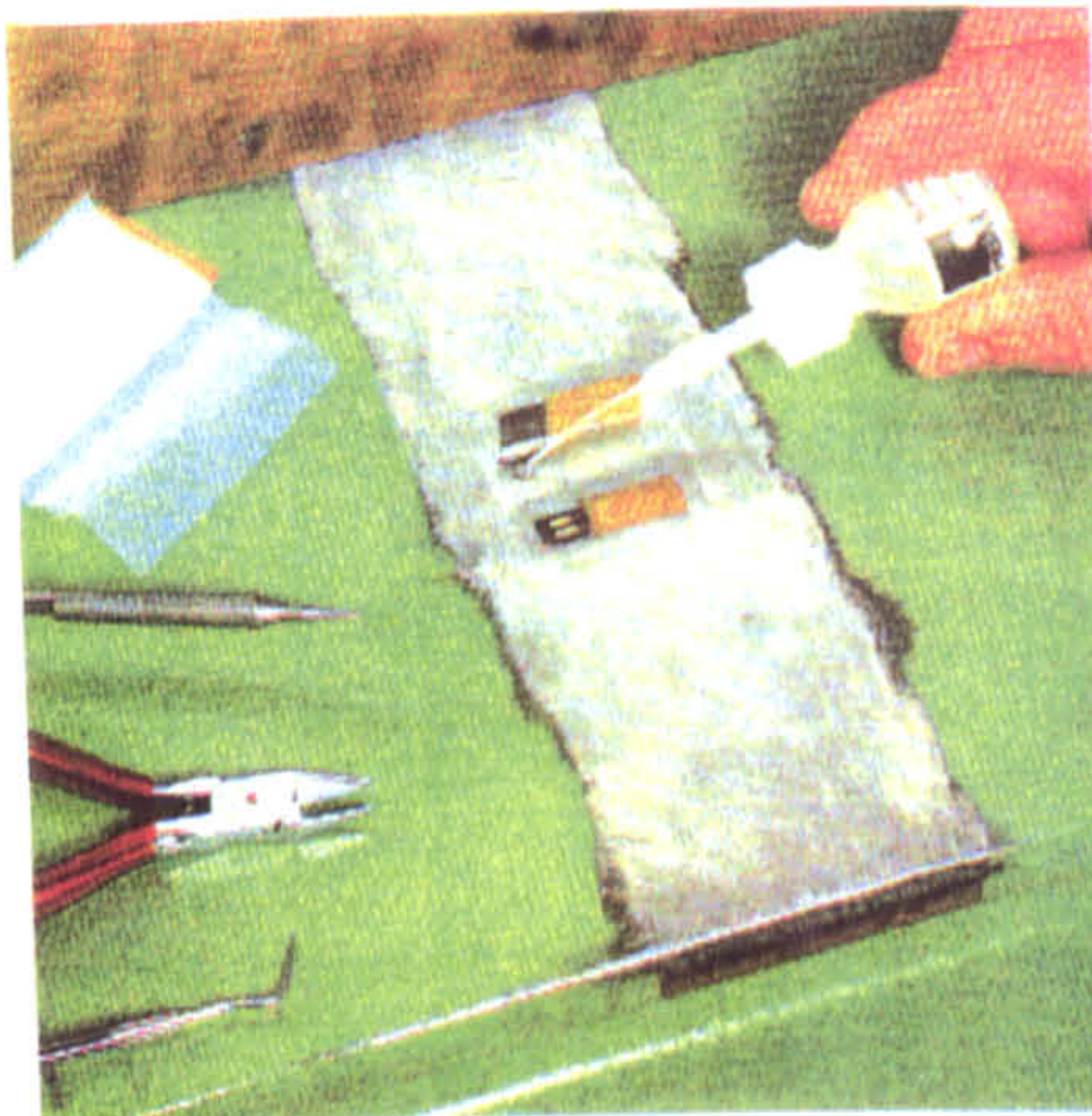
1. Roughening of the application area



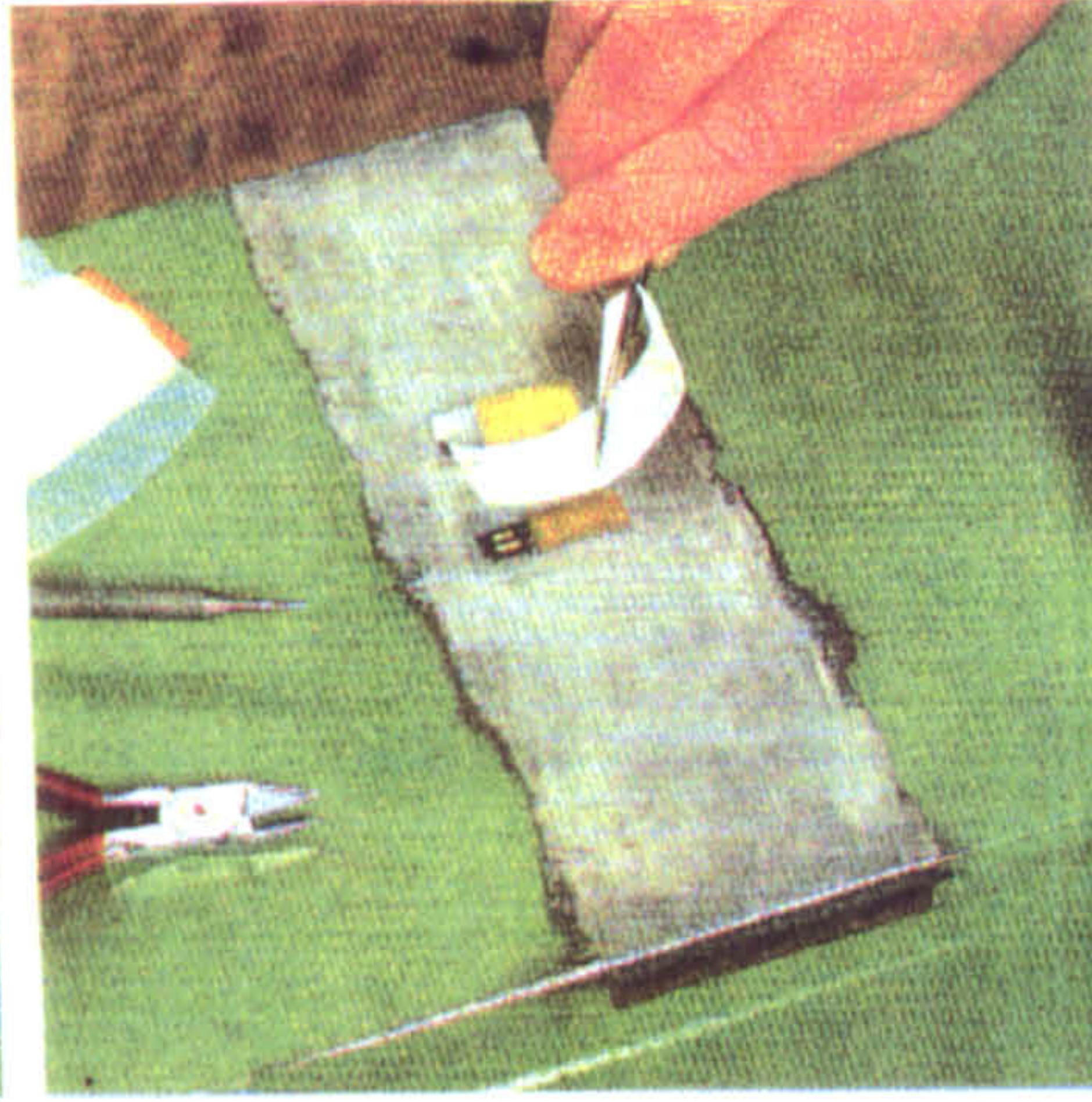
2. Cleaning of the application area



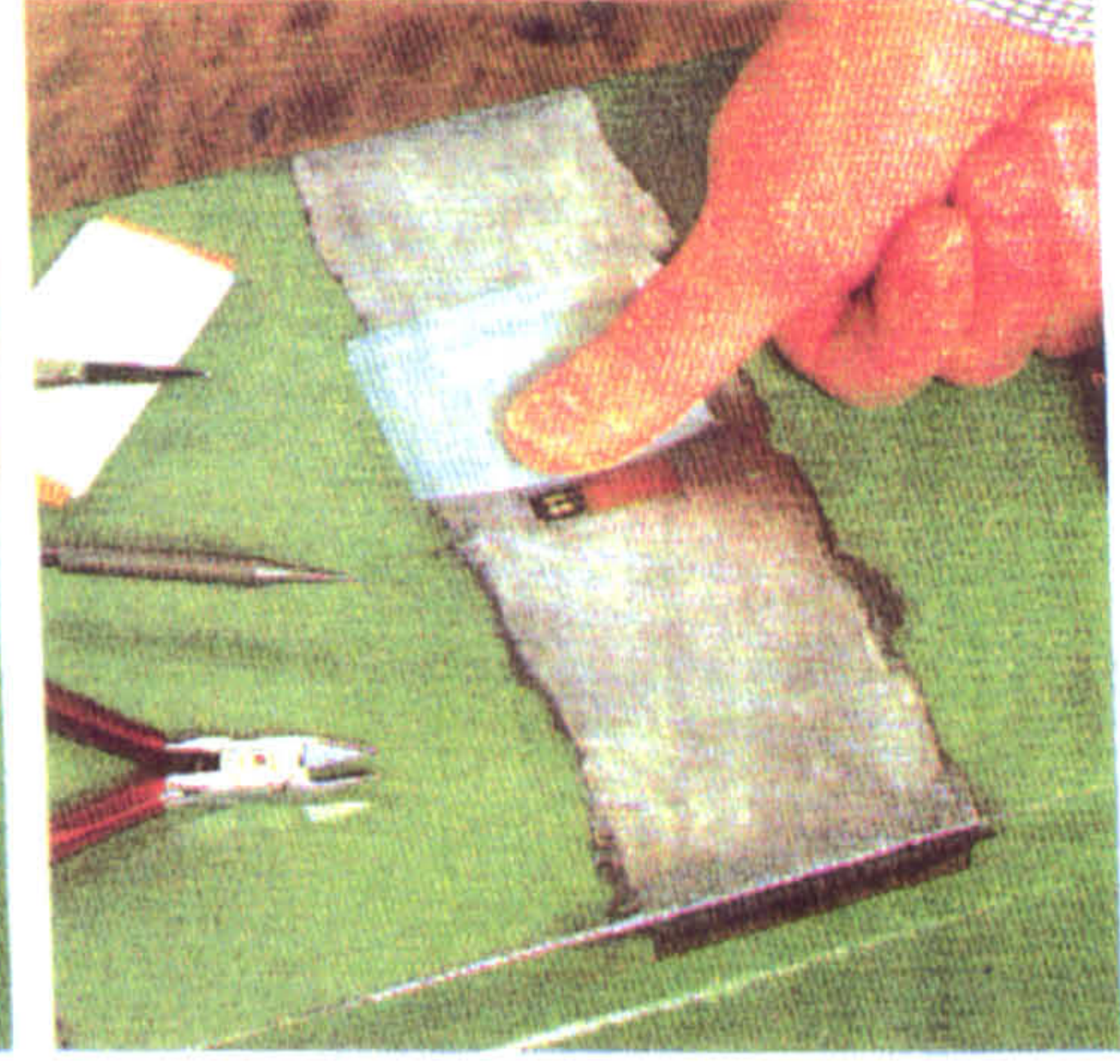
3. Positioning of the strain gauges with tape



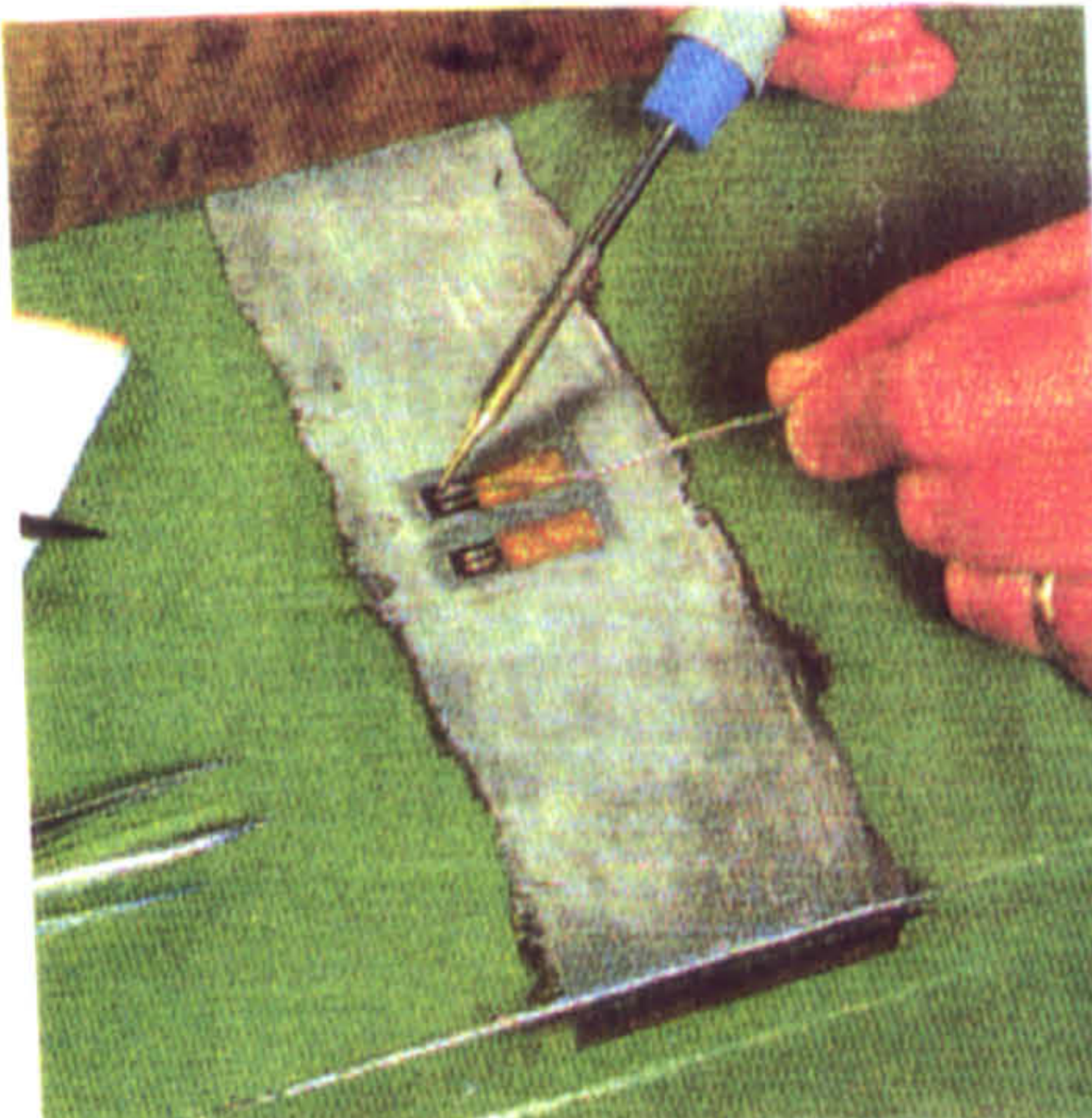
4. Applying the adhesive



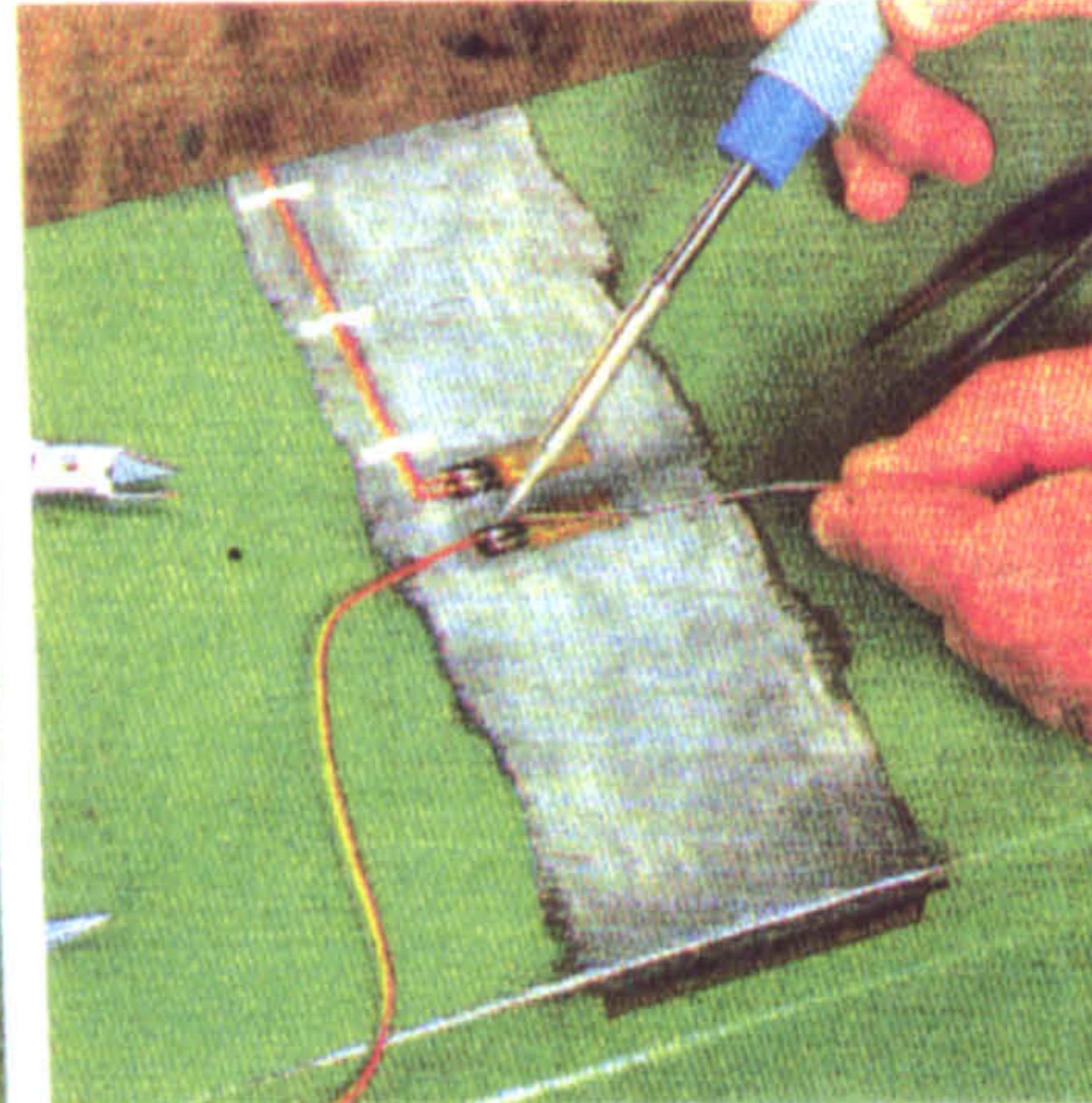
5. Spreading the adhesive



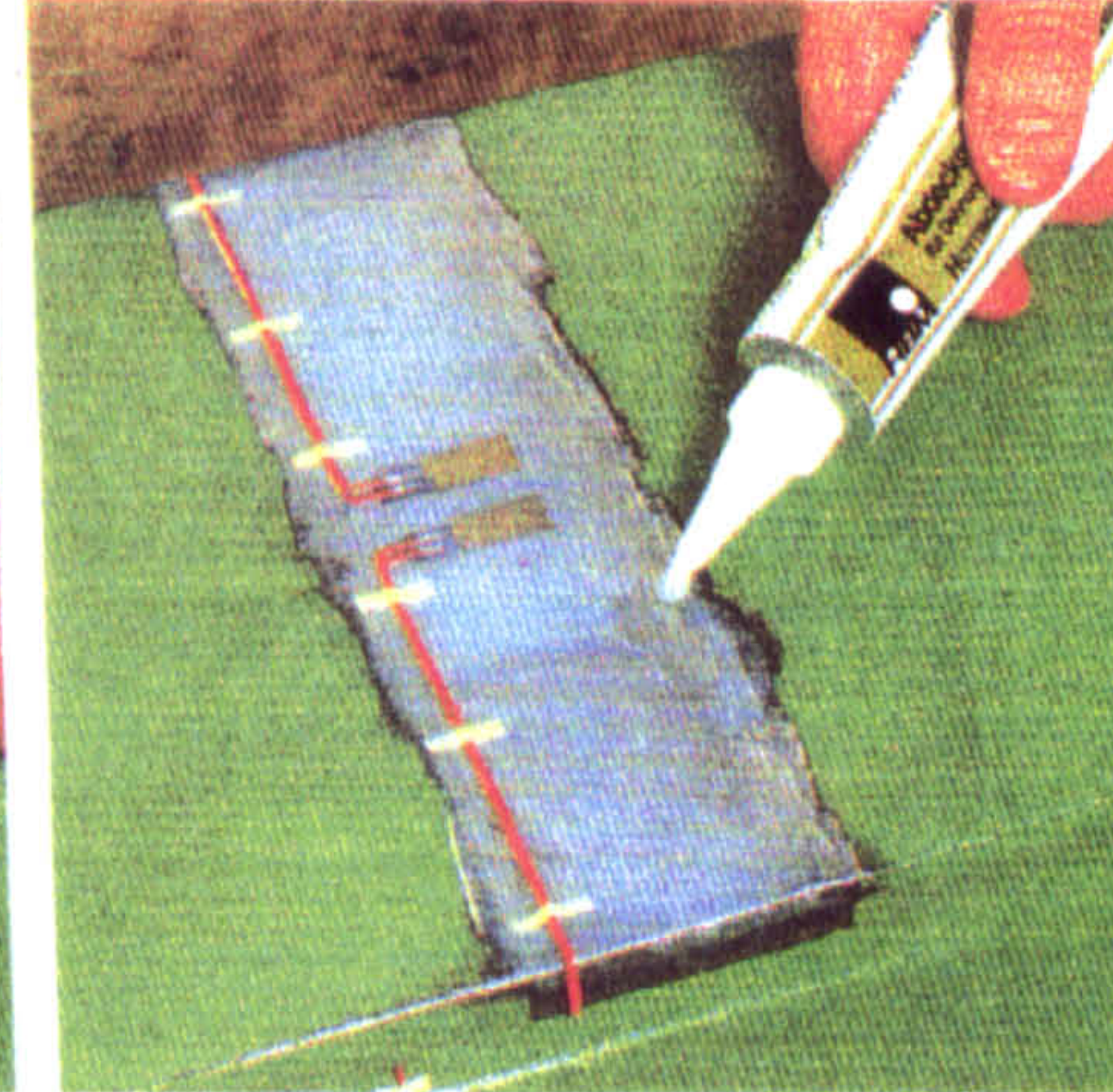
6. Pressing the strain gauges



7. Soldering the strain gauge ribbons



8. Soldering and fixing the cables



9. Covering the measurement point

Figure 10 Stage-by-stage application of Strain Gauge

From HBM Strain Gauges and Accessories

3.7 The Wheatstone Bridge

Bridge circuits are widely employed for the measurement of resistance capacitance and inductance. The simplest resistance bridge is pictured below. V out, in the centre of the circuit, can be either of alternating or direct current, to measure a resistance transducer such as a strain gauge.

The Wheatstone bridge circuit enables resistance to be measured more accurately than by ammeter/voltmeter. It involves making adjustments until V out shown in Fig 11 below is nill. Four resistors, P, Q, R, and S are joined at 45° to each other as shown in figure 11:

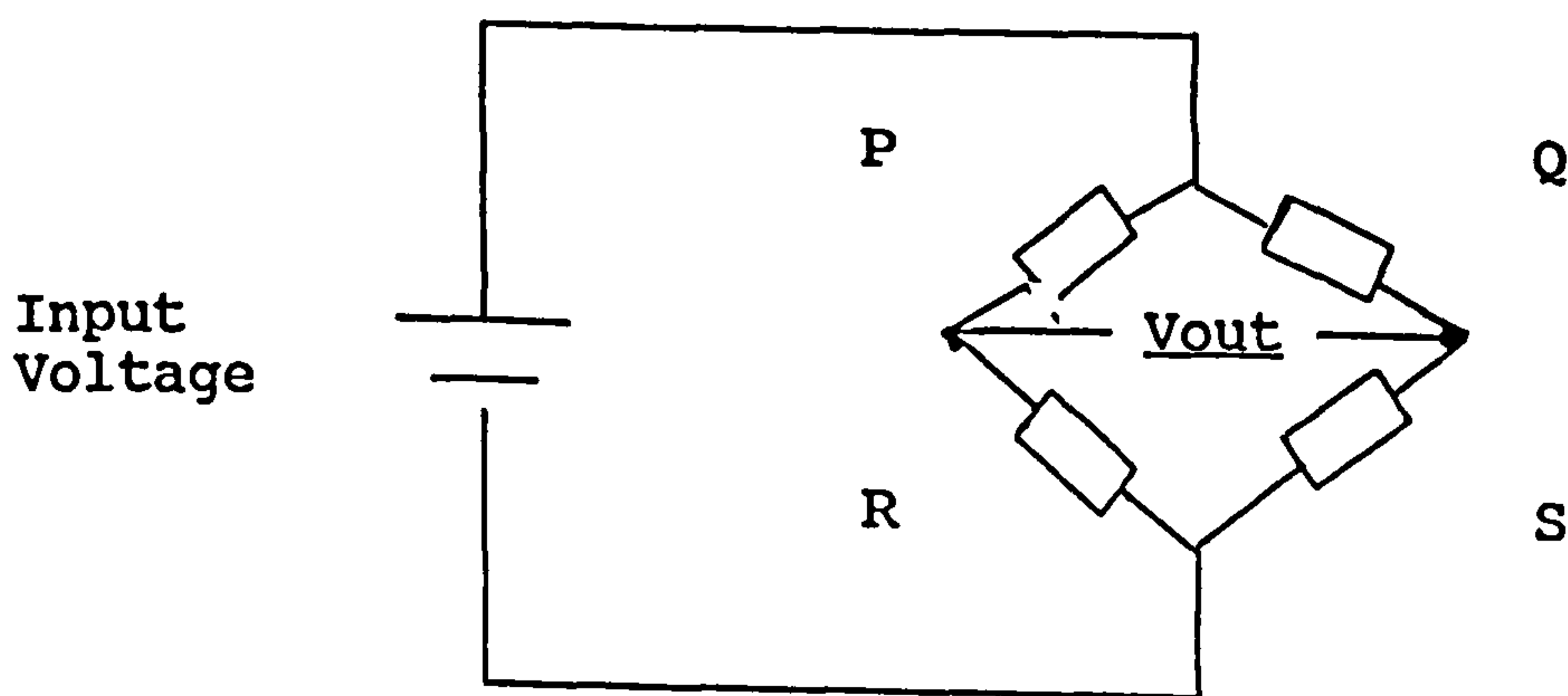


Figure 11 Wheatstone Bridge

If resistor P is unknown, then Q must be known, as must the values of R and S, or their ratio. One or more of the resistors Q, R and S are then adjusted until V out is nill. The bridge is then said to be balanced and the following equation then applies:

$$\frac{P}{Q} = \frac{R}{S}$$

3.8 Instrumentation Amplifier

Since the electrical signals produced by the Wheatstone bridge are of a low voltage, it is necessary to amplify them before they are suitable for further processing and recording. The instrumentation amplifier should have the following properties:

1. Large band-width.
2. High input-impedance.
3. An adjustable and stable differential gain.
4. A high common mode rejection ratio.
5. Low input drift.
6. Low output impedance.

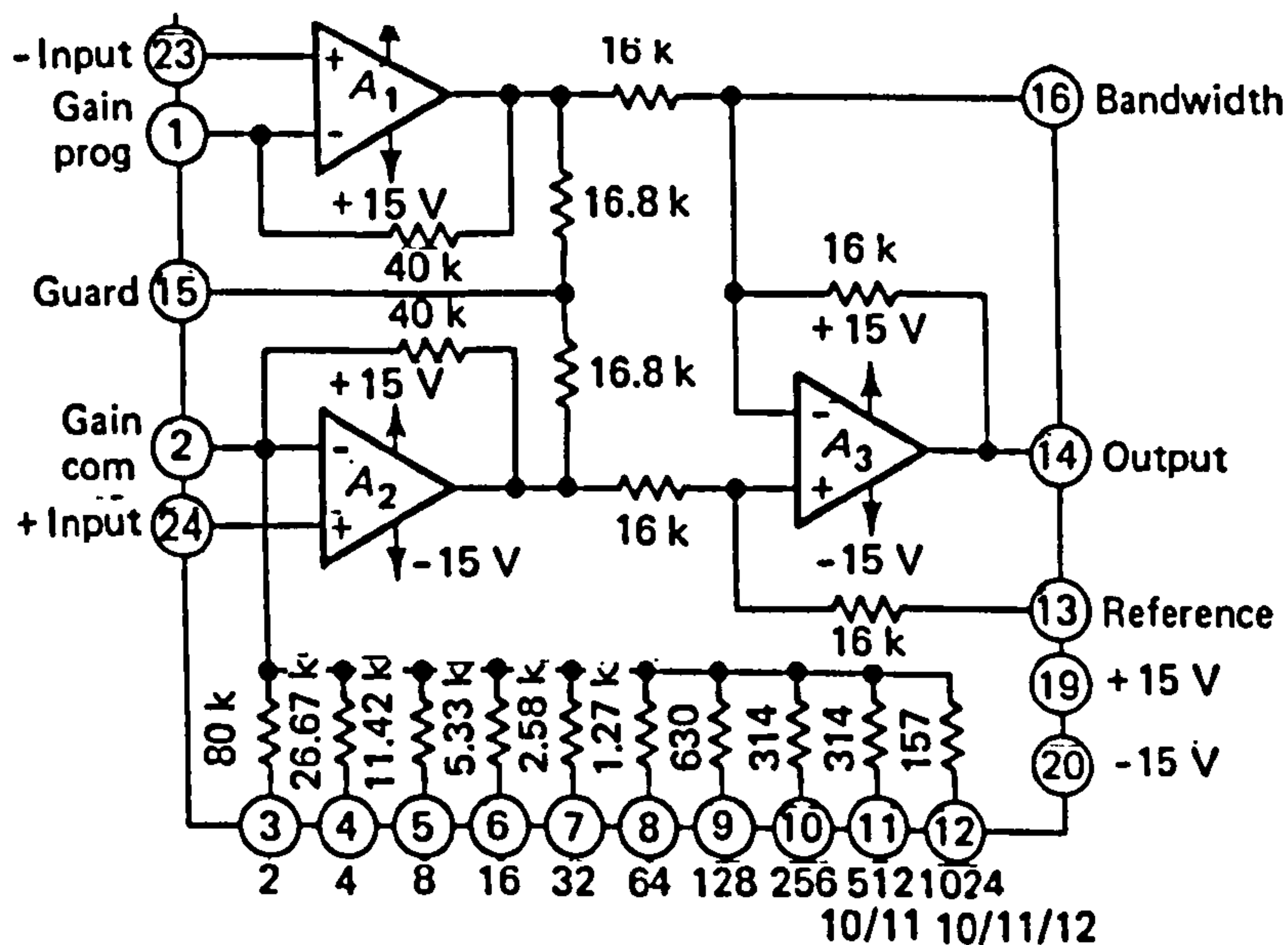


Figure 12 Instrumentation amplifier

CHAPTER 4

Chapter 4

The practical development of an Allergic Testing System

The theoretical work involved in producing a system to measure muscle strength has been discussed in the previous chapter. The practical work of developing the system has been divided into two main sections. The first section covers the mechanical development i.e. converting muscle power into mechanical power.

The second section covers the electrical development i.e. converting mechanical power into an electrical signal.

In both of the sections the various stages of development of all prototypes and the steps taken to build a final, reliable and fully-functioning system are discussed.

4.1 Mechanical Development

This section looks at converting muscle power into mechanical energy. Much thought was given to developing such a system. Many systems were considered, some already existing as complete systems, others were developed during the course of the work in this thesis. The principles of operation, advantages and disadvantages of each of the systems are discussed, but first the structure and function of the muscle itself is reviewed as it is the source producing the mechanical power.

4.1.1

Definition of a muscle

Muscles are composed of cells in which the capacity of protoplasm to contract has become highly developed and has been given direction. Most muscle cells are long and thin and therefore receive the name of fibres; they react to appropriate stimulation by shortening along their long axis.

When stimulated a muscle fibre contracts, the natural stimulus arrives via the motor neurone, but the muscle will respond to an external stimulus such as an electrical current.

When a muscle is being stimulated via its motor nerve a localised potential appears at the motor end-plate with each nerve impulse. When this end plate potential reaches a critical magnitude a propagated muscle action potential is produced which spreads over the muscle fibre. A stimulus giving rise to a single nerve impulse gives a single muscle action potential which occurs at the onset of the contract phase of the muscle.

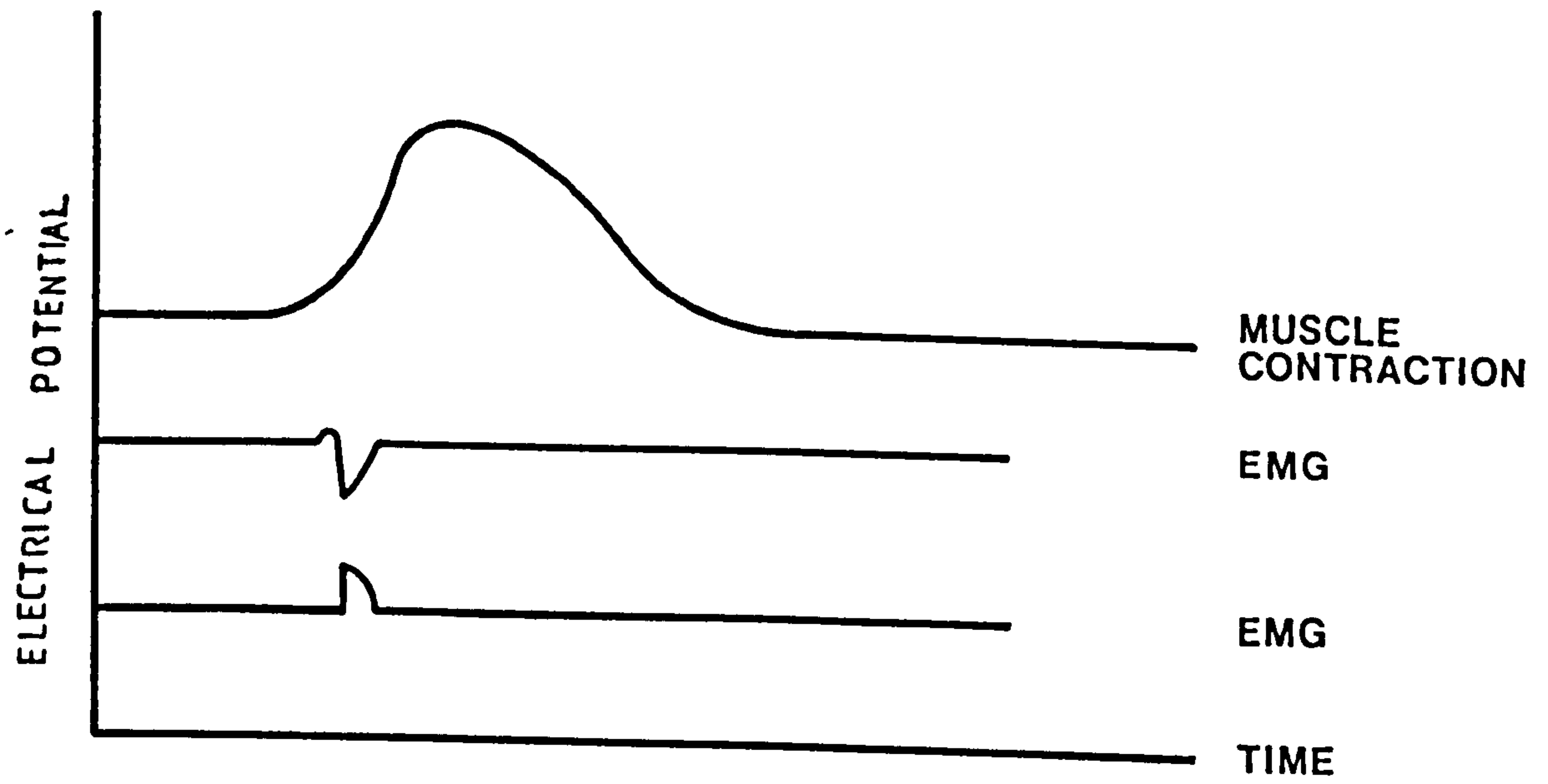


Figure 13 Shows the output of EMG as muscles contract

Muscle contraction may be static or isometric, that is to say the length may remain constant but the tension increases, or it may be dynamic or isotonic, that is to say the muscle becoming shorter and thicker. There is a fine interval between the application of a stimulus and the onset of a contraction. This interval is known as the latent period. There then follows a contraction phase followed in turn by a relaxation phase.

Muscle requires approximately fifty times more oxygen per minute when active than when at rest. Muscles contain 400g of glycogen which is used up during muscular activity and replenished after exercise from the blood glucose. When a muscle is active, the glycogen stores are depleted, oxygen is used up and carbon dioxide is formed. Muscle glycogen breaks down to pyruvic acid with the release of energy. The pyruvic acid is further oxidized to CO_2 and H_2O . The energy developed by the muscle action is converted in part to mechanical work and in part to heat and since the muscles have a maximum efficiency of 25% that implies that at least three-quarters of the energy is lost as heat.

4.1.2 The Isokinetic System

The particular isokinetic system which is considered here is the Cybox II Plus System. It has been extensively used for rehabilitation in clinical testing and research. It is the only system that will allow the precise measurement of dynamic functional capability of every major body joint and muscle group. The system could be described as a very complex dynamometer.

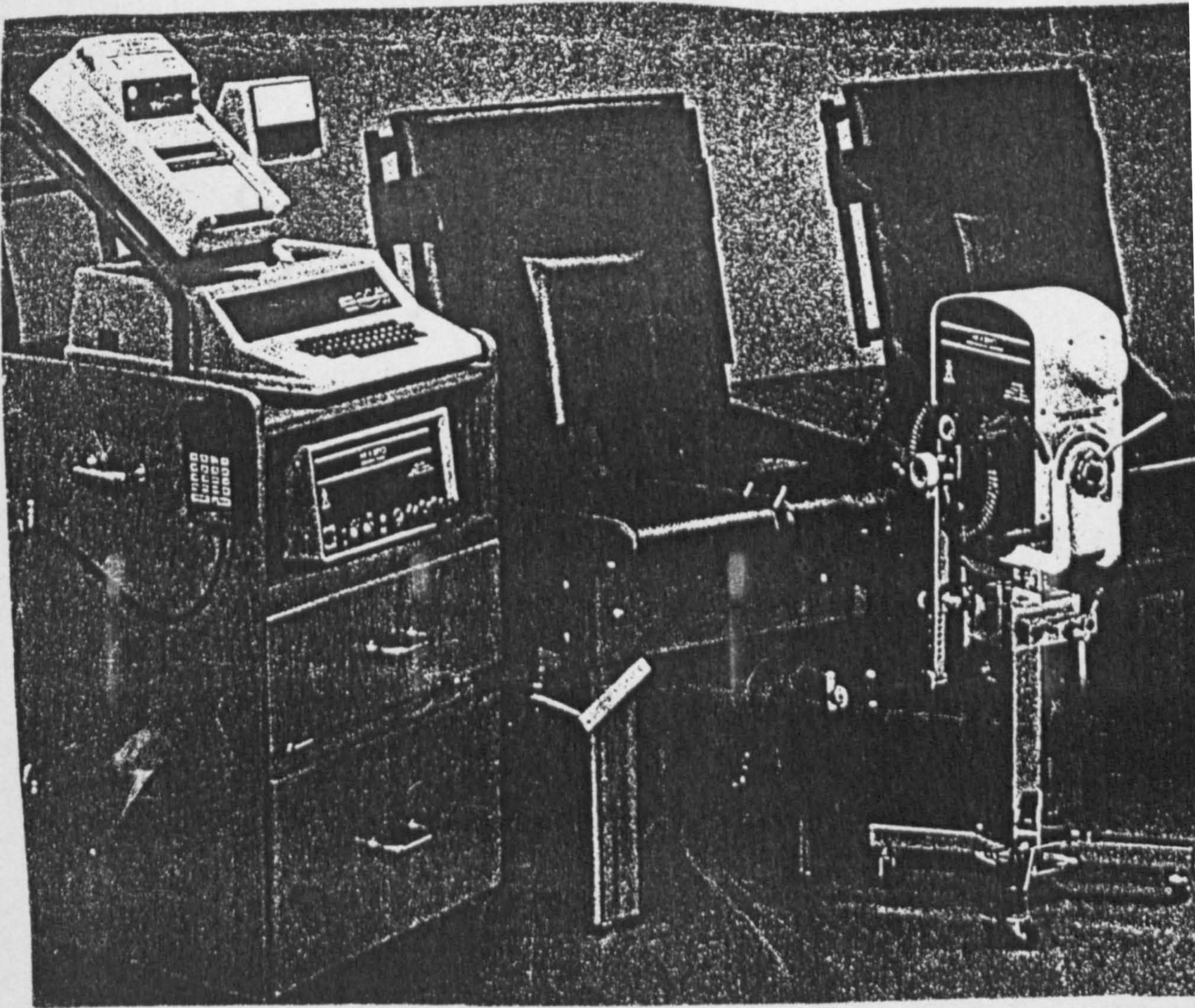


Figure 14 Shows a commercial isokinetic system
(Cybox 11 Plus system)

Although this is a readily available system to measure muscle strength of the quadriceps and the hamstrings of athletes it could be used to measure the strength of the arm by simply moving the position of the pedal. It would be possible to use the system to measure the effect of an allergen on muscle strength, the machine gives results graphically.

However, the machine was not designed to be easily portable in that once it has been set up in a given area it is usually meant to stay there. Also the cost of the machine is in excess of £2,000.

The above system was used by the author to develop a mathematical model for the muscles of the quadriceps and the hamstring during his MSc. dissertation. The system (Figure 15) was used to measure the torque of the quadriceps and the hamstring and a graph was presented of torque against the angle of the knee as shown in figure 16.

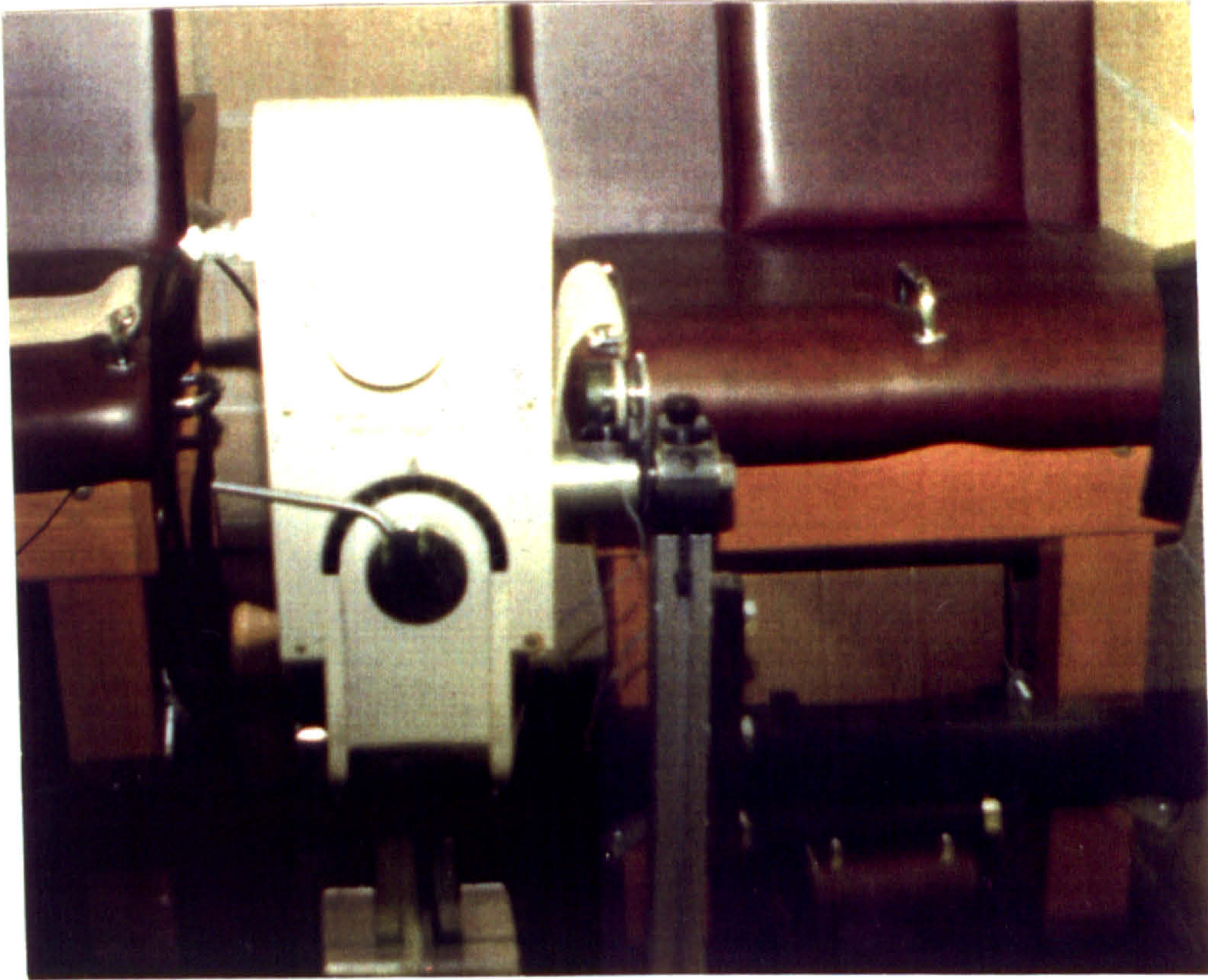


Figure 15 Shows an isokinetic system (Cybox 11 plus) used by the author for his M.Sc. to develop a mathematical model for the quadriceptal hamstring

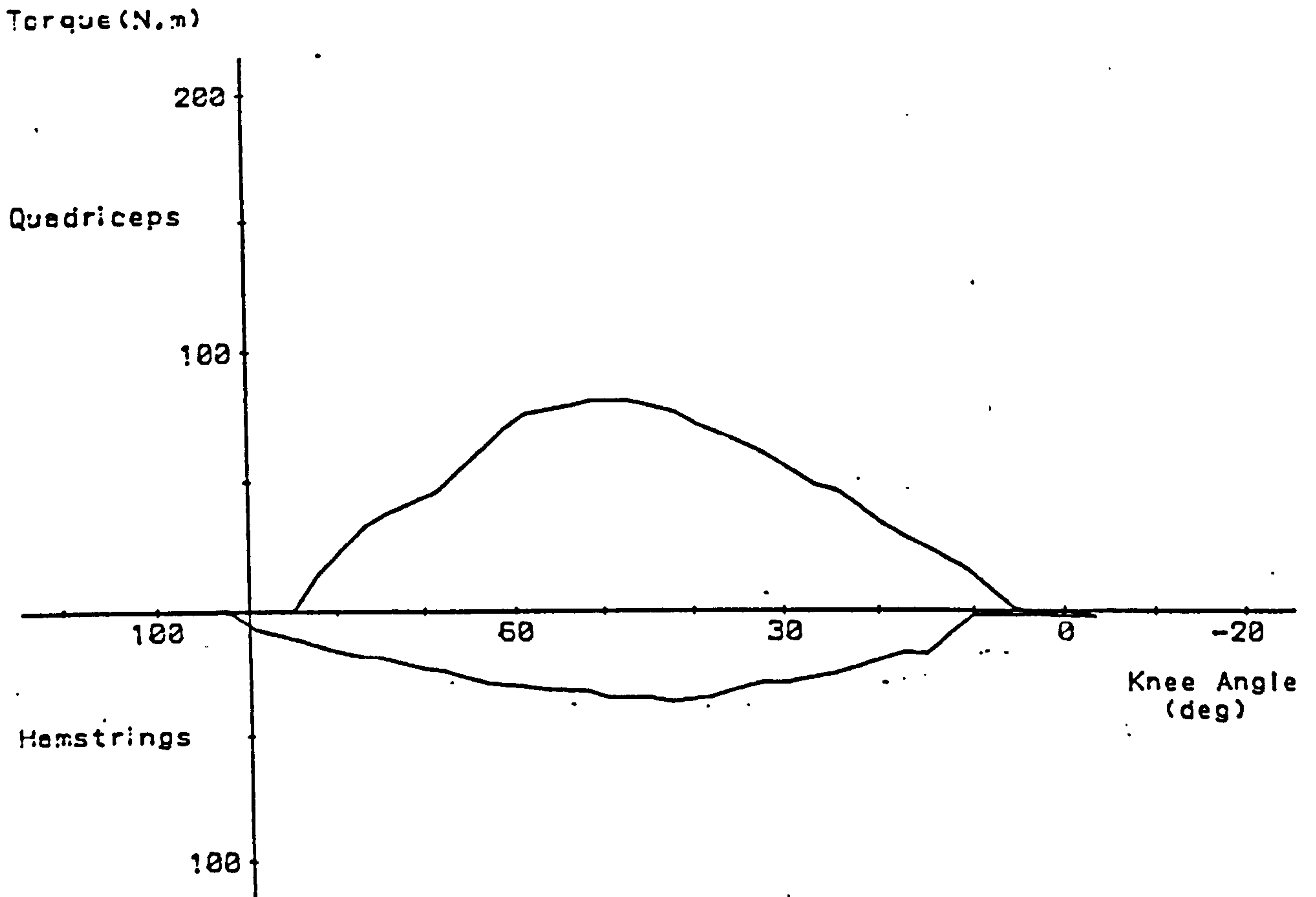


Figure 16 A result obtained from the isokinetic system (from the author's M.Sc. dissertation). This shows the torque of the quadriceps and hamstrings against the angle of the knee. This test can be done for the left and right knee separately. The upper curve is extension, the lower is contraction.

4.1.3 The Straight Arm Pressure System

This idea was not actually developed as a better solution was found but the theory is relevant and therefore should be discussed. As the name suggests, the subject holds out at shoulder height the outstretched arm. The subject then grips with the hand of the outstretched arm the handle of the 'pressurised' stand. In the free hand, held against the side of the body, is held an allergen.

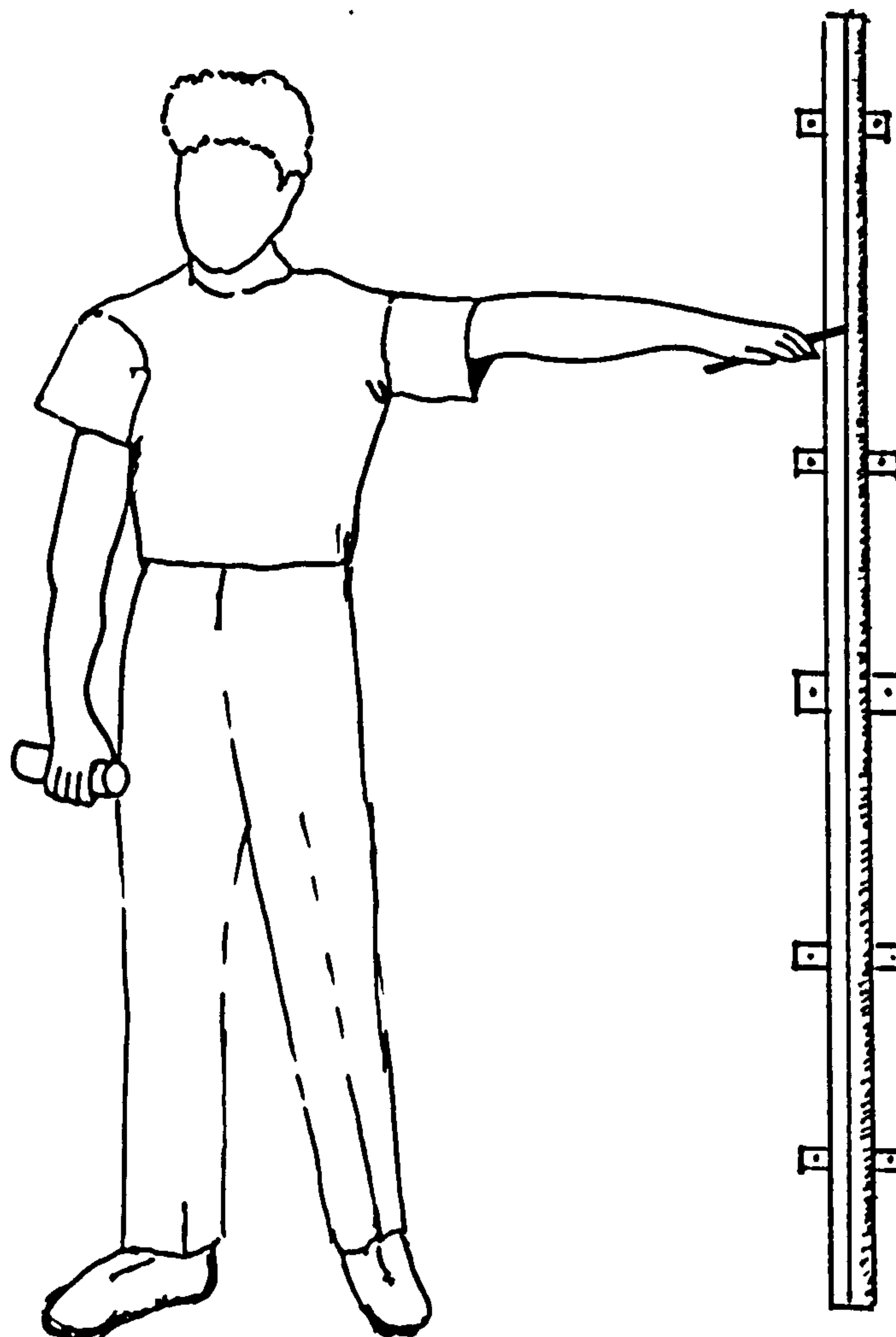


Figure 17

The Straight Arm Pressure System
An illustration of a patient applying pressure to the pressurised stand.

The principal behind this is that the pressure in the stand is adjusted to equal the natural resistance of the subject's outstretched arm. Along the side of the pressure stand is a graduated scale which one can read. When an allergen is introduced that the subject reacts to, the variation in pressure gives a physical displacement that can be seen and the difference between the original reading and the final reading can then be recorded.

The main reason why this system was not actually produced was that it would have been highly immobile. As the stand had to be pressurised by either air or oil, it would have been necessary to have the stand bolted to the wall or floor.

4.1.4 Pressure Sensor

Taking into account the previous two systems, it was decided that the system would ultimately have to be easily transportable and give accurate results at a low cost.

For the above reasons a pressure sensor was developed. The final version of the pressure sensor has gone through four different stages of development. Each of the prototypes' operation characteristic advantages and disadvantages are described.

(i) Prototype 1

The principle behind this prototype (Figure 18) is that the thumb would apply pressure to the strain measuring

area, and from here the mechanical energy would be converted into an electrical signal via a strain gauge. It started with a piece of stainless steel 3mm thick, this was then formed into a U-shape. A thin wafer was then attached to the U-shaped component with machine screws. The following diagram shows this and the dimensions of both components.

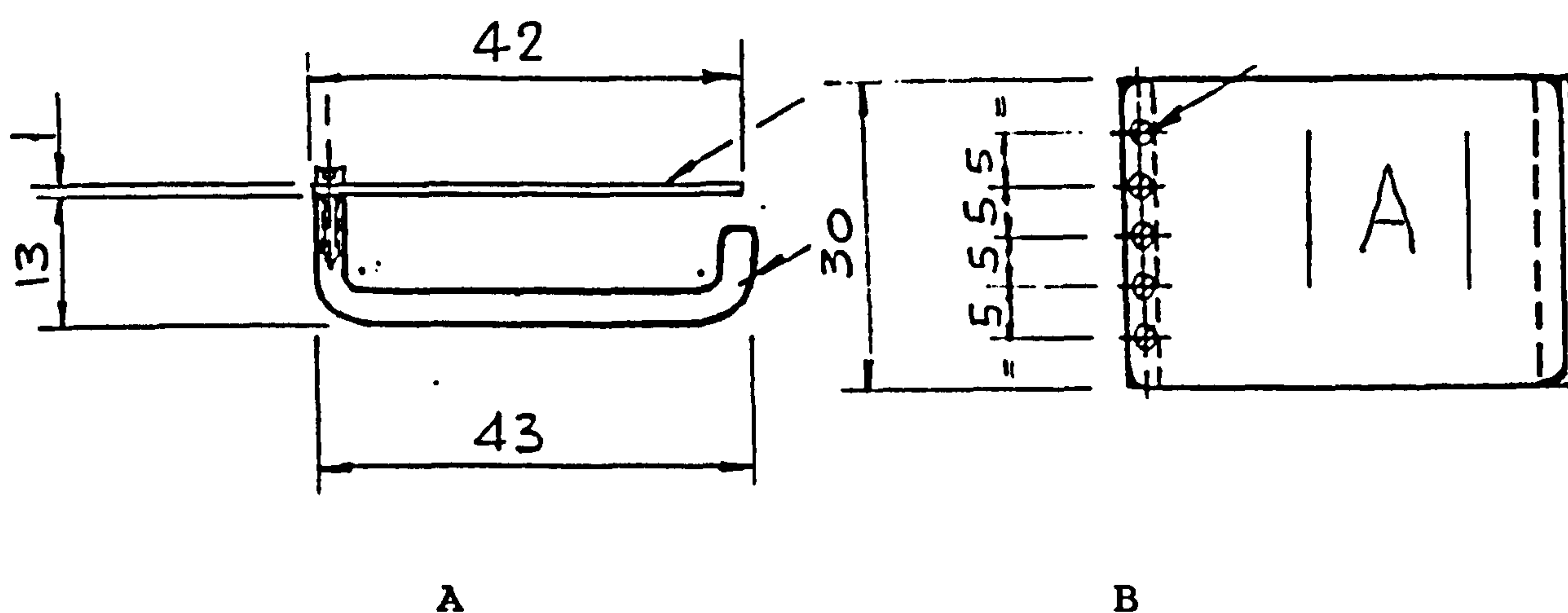


Figure 18 An illustration of Prototype 1.
 A: shows Prototype 1. Main body of the draft drawing of Prototype 1 in Appendix 1
 B: shows the thin wafer which can be attached to the main body

As it was stated earlier a piece of 3mm stainless steel was used for the main component, but it was not yet known what to make the thin wafer out of. Several materials were considered: perspex, copper, stainless steel and spring steel. The wafer had to retain its original properties after pressure had been applied to it and then released. That is to say, it had to return to its original position

without bending or distorting when pressure was applied to it.

Table No. 2, shows the results obtained after testing the materials copper, perspex, stainless steel and spring steel under pressure. The tests were carried out at room temperature over a period of approx 1 hour. The test consisted of a wafer of the material being attached to the main component, as shown in figure 18(a), and pressure applied to a specific point, marked by the letter A, see figure 18(b), and then pressure was released. The test was then repeated after 2 seconds. It was repeated for each of the materials until it either bent or distorted or would not return to its original position.

The volunteers used in this test were of different sex, ages, height and weight.

SEX	AGE	HEIGHT	WEIGHT
Male 1	26	5' 9"	12 st
Male 2	28	5' 7"	10 st
Female 1	22	5' 4"	8 st

<u>MATERIAL</u>	<u>MALE/FEMALE</u>	<u>NO. OF TIMES PRESSURE APPLIED BEFORE DESTRUCTION</u>
Copper	Male#1	2) the wafer did not
	Male#2	2) return to its
	Female#1	2) original place
Perspex	Male#1	4) the wafer is
	Male#2	7) liable to be
	Female#1	16) destroyed if too much pressure is applied
Stainless Steel	Male#1	2) the wafer did not
	Male#2	2) return to its
	Female#1	2) original place
Spring Steel	Male#1	on all, the wafer
	Male#2	did return to its
	Female#1	original position

Table 2 Shows Testing of thin wafer materials.

As could be seen from the table of results it was decided to use spring steel for its ability to return to its original shape. Spring steel has a very high carbon content, is usually of a very high quality and is quite expensive. However for the piece required the cost was minimal. Prototype 1 (Figure 19) with its spring steel wafer now attached was shown to Drs Choy and Brostoff. Their comments were that not much consideration had been given to the difference in muscle strength between the thumb and forefingers of different subjects. Their suggestion was to develop a system that would measure the strength of the outstretched arm of the subject.

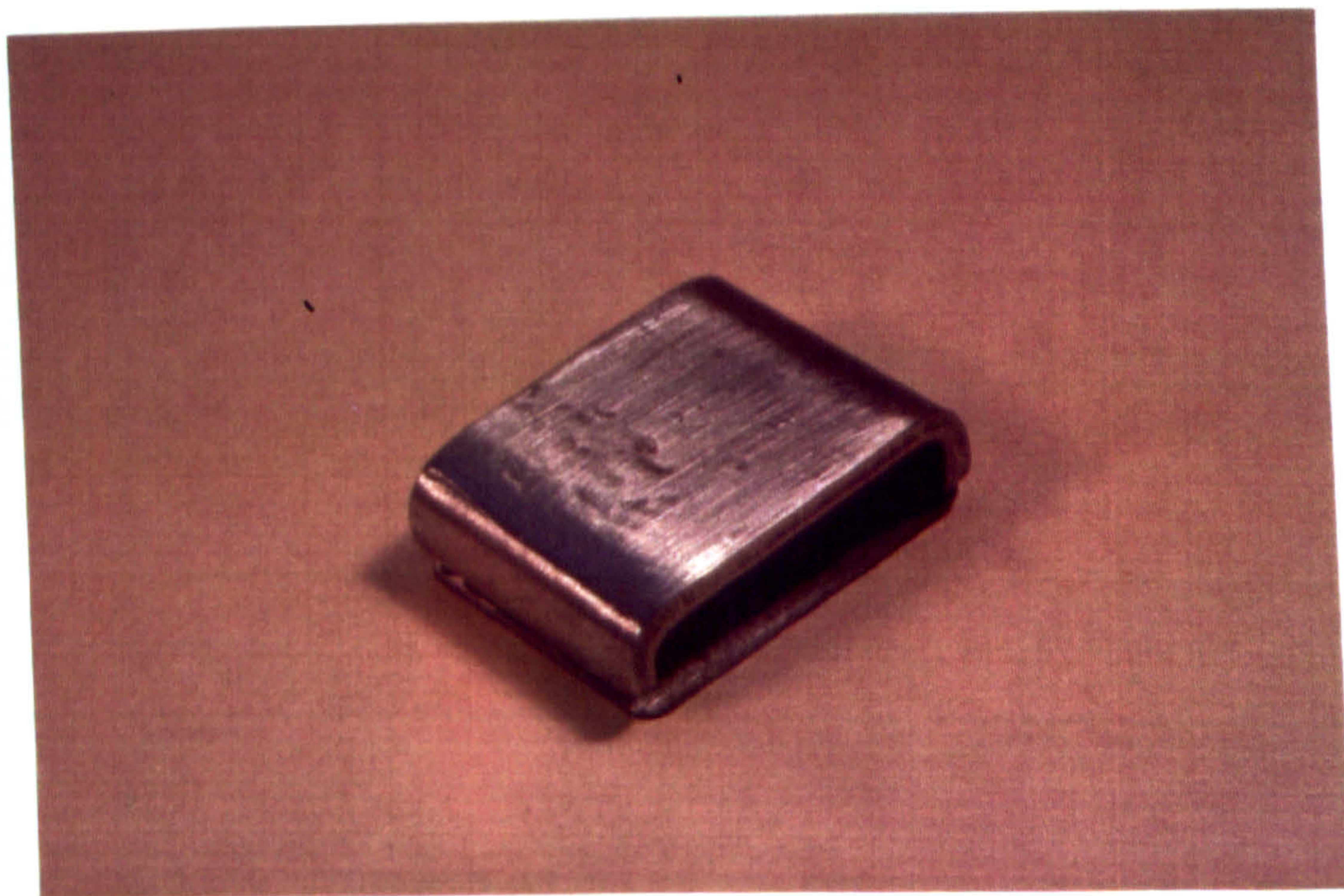


Figure 19 Shows a picture of Prototype 1

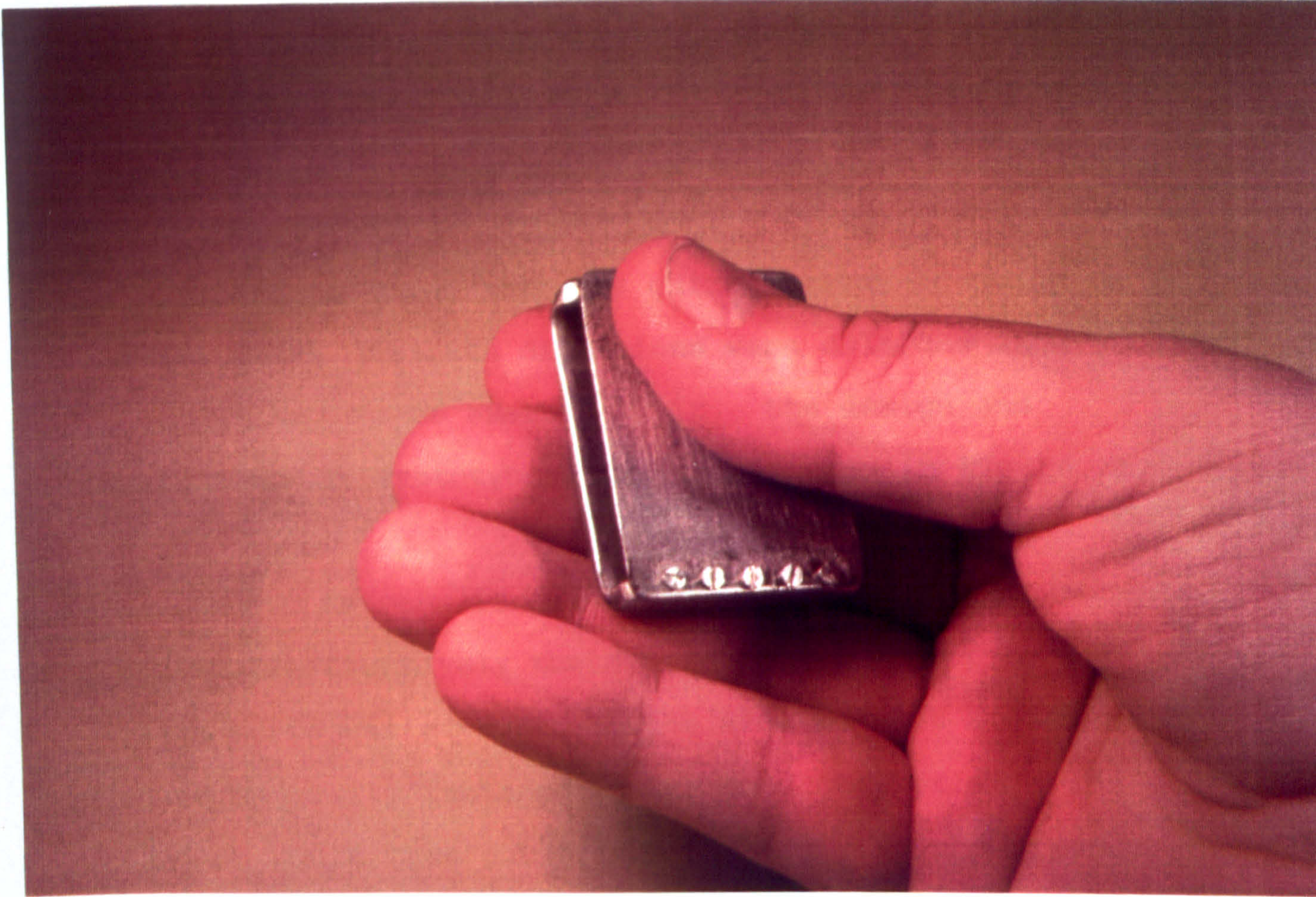


Figure 20 Shows a picture of patient applying pressure with the thumb to pressure sensor (Prototype 1)

(ii) Prototype 2

Prototype 2 was designed so that it could be attached to the patient's wrist so the muscle strength of the outstretched arm can be measured. Taking into account the positive elements of Prototype 1: compactness and portability, these were to be incorporated into Prototype 2.

Prototype 2 was actually quite similar in shape to Prototype 1, just its dimensions were enlarged as a greater pressure was to be exerted on it. the design and dimensions of Prototype 2 are shown below in Figure 21.

As can be seen it consisted now of 4 major components, but still effectively the same shape as Prototype 1. A watch strap was attached to the side so that Prototype 2 could be easily fastened to the subject's wrist. The subject would then outstretch the arm with the Pressure Sensor Prototype 2 attached to the wrist and would hold the respective allergen in the other hand. A strain gauge was attached to the spring steel wafer, as it was found in tests carried out on patients, provided by Dr. Choy, that there is a variation in the strength of arm from one patient to the other. A new component was needed to be added to prototype 2, this consisted of a brass lug with a hole drilled in it (see Figures 22 and 23) machined to fit

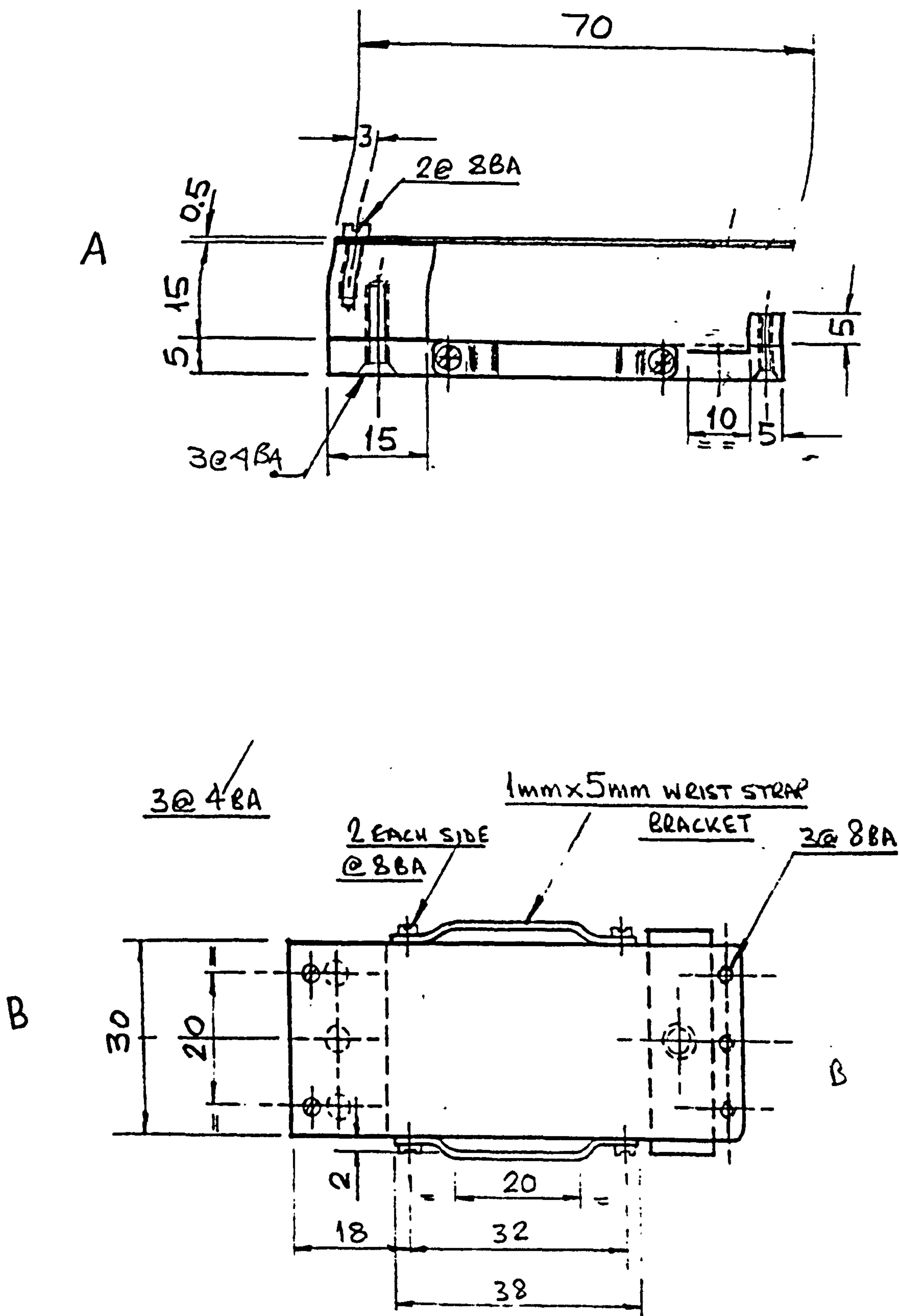


Figure 21 Shows an illustration of pressure sensor Prototype 2

A Side view

B Top view

(Draft drawing of Prototype 2 available in appendix)

comfortably to the right hand side of prototype 2, as shown in figure 24. In the hole of the lug a spring was inserted, one of several differing in strength. This design proved to be a little too cumbersome, having to change the spring to a greater or lesser strength with differing subject arm length. To operate the system effectively a third party was required to apply pressure to the top of prototype 2 (see Figure 25). The person applying the pressure needed to be very experienced in knowing the correct amount of pressure to apply. If too much was applied or for that matter too little, the reading that would follow would be wholly inaccurate. Because of the above reasons this prototype was not developed further. A new solution had to be found which lead to a new prototype, i.e. using the muscle between the thumb and the first finger.

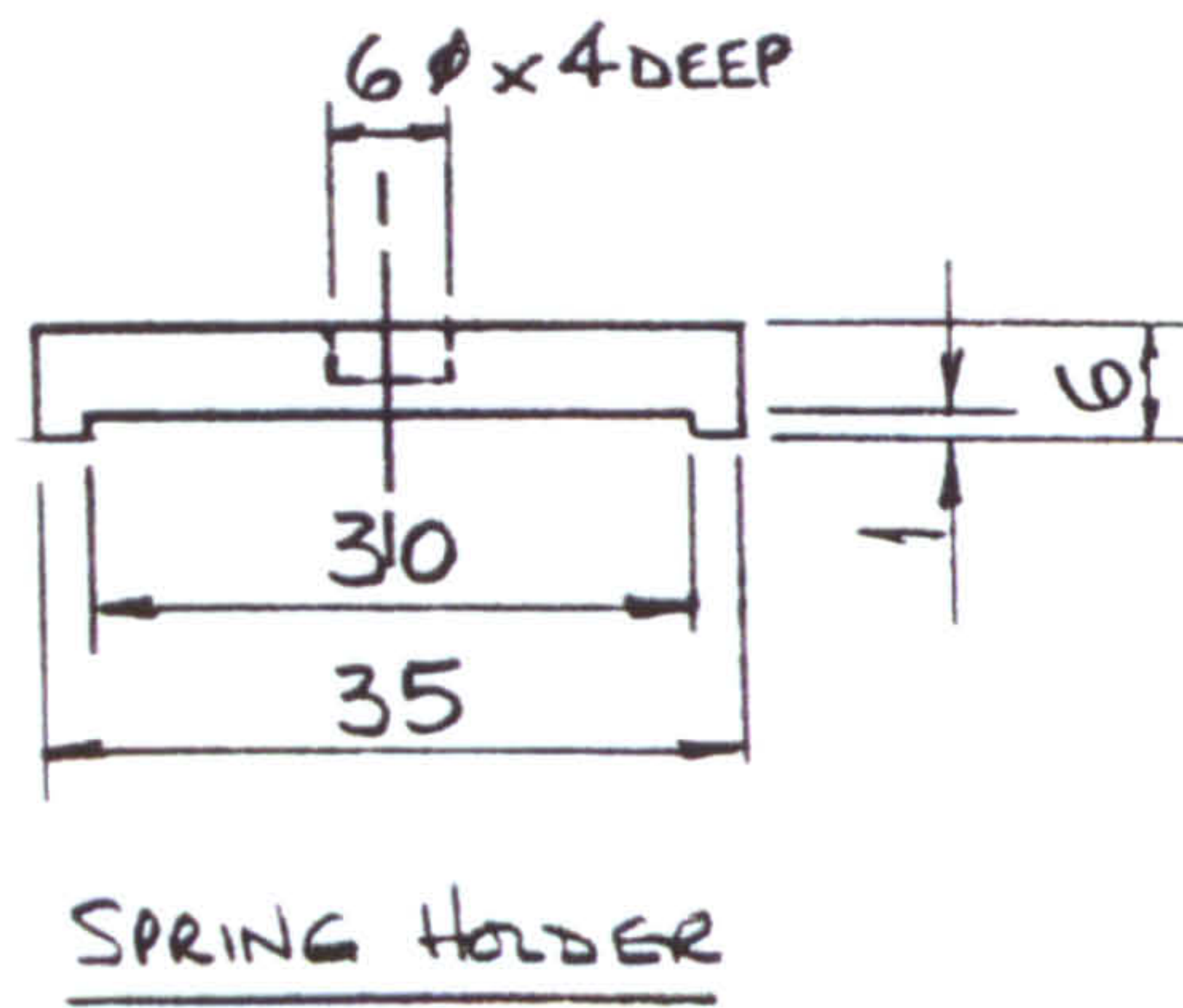
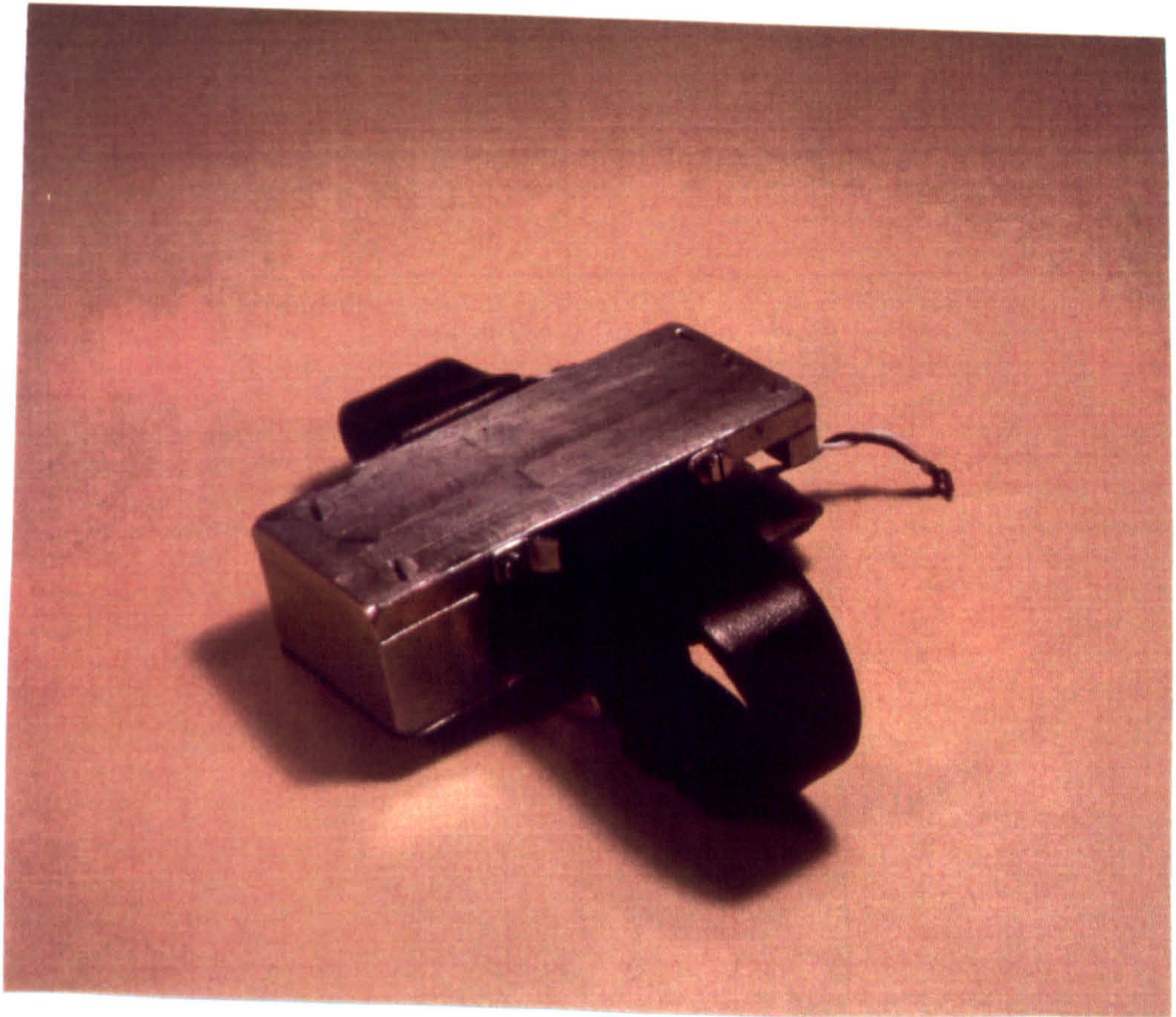


Figure 22 Showing dimensions of Spring Holder



Figure 23 Close up detail of Spring Holder used with Prototype 2

A



B

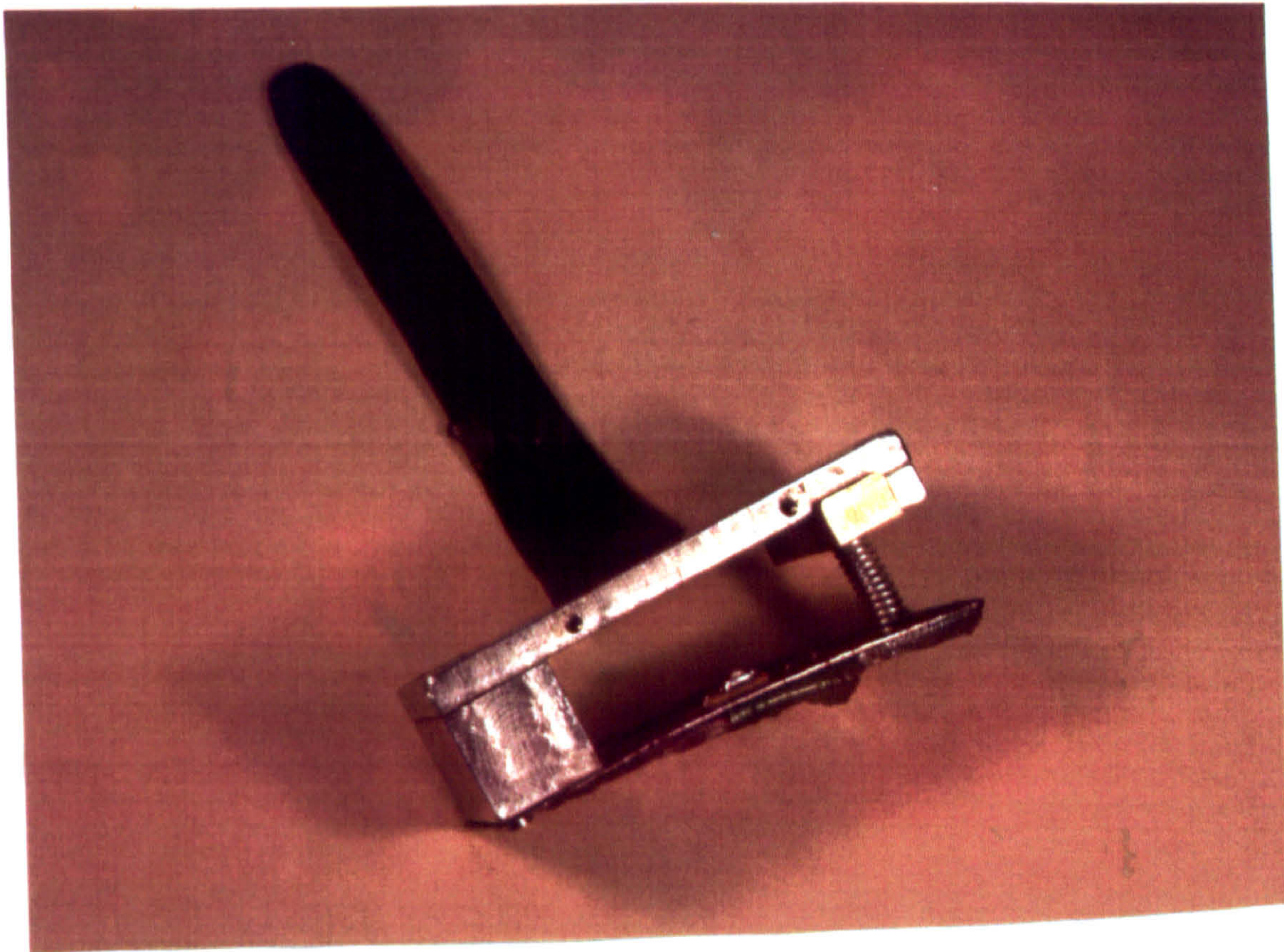


Figure 24 Shows pressure sensor prototype 2 with the spring holder

A - top view
B - side view

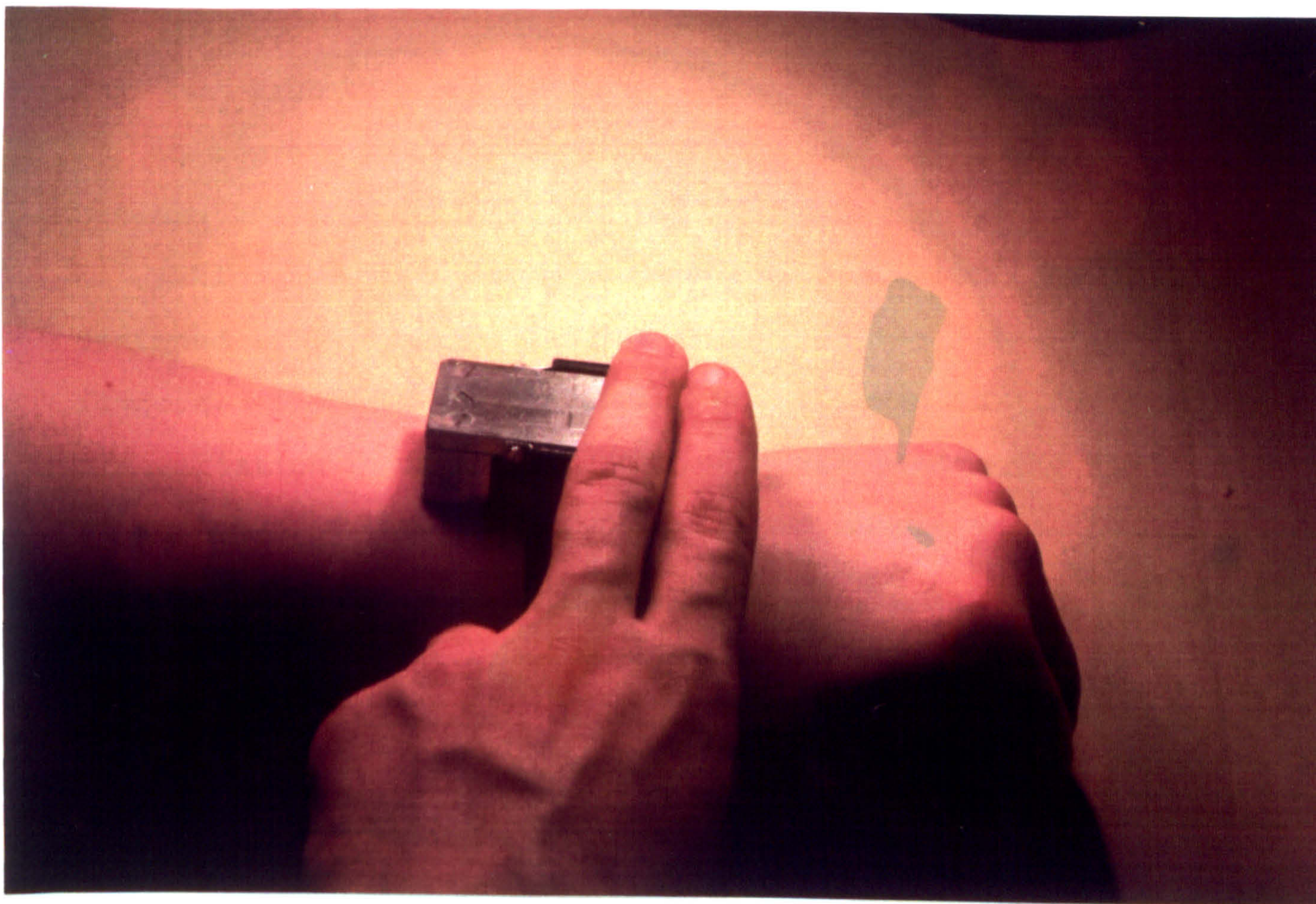


Figure 25 Shows a picture of a clinician applying pressure to pressure sensor (prototype 2)

(iii) Prototype 3

This prototype will be used to measure the power between the thumb and the two next fingers.

Taking the basic design of Prototype 2, Prototype 3 was designed to be used between the thumb and the first two fingers. In Prototype 2 a spring was allowed to allow for the variation in muscle strength. An air piston was used in Prototype 3 to allow for the greater muscle variation as shown in figure 27.

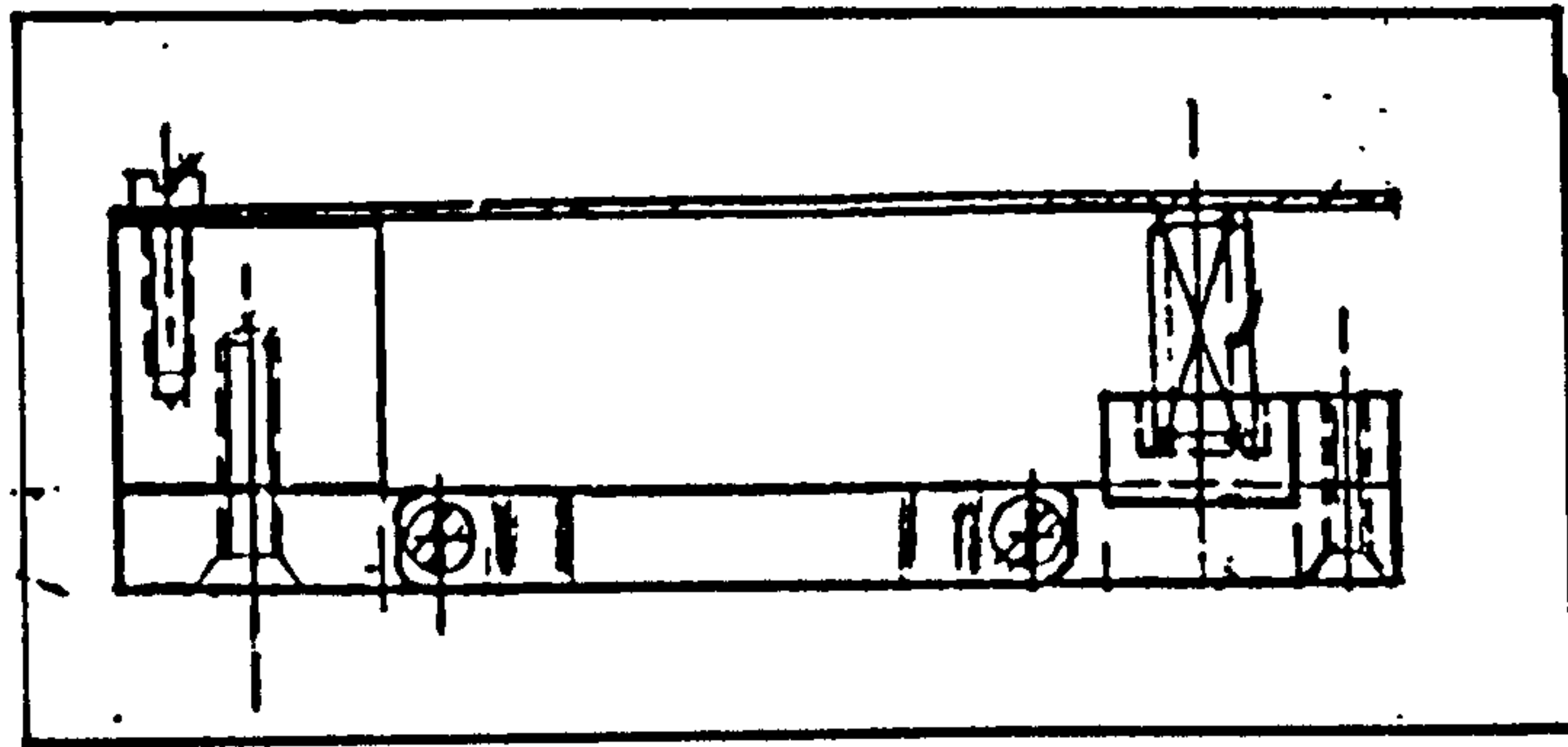


Figure 26 Main Body of Prototype 2

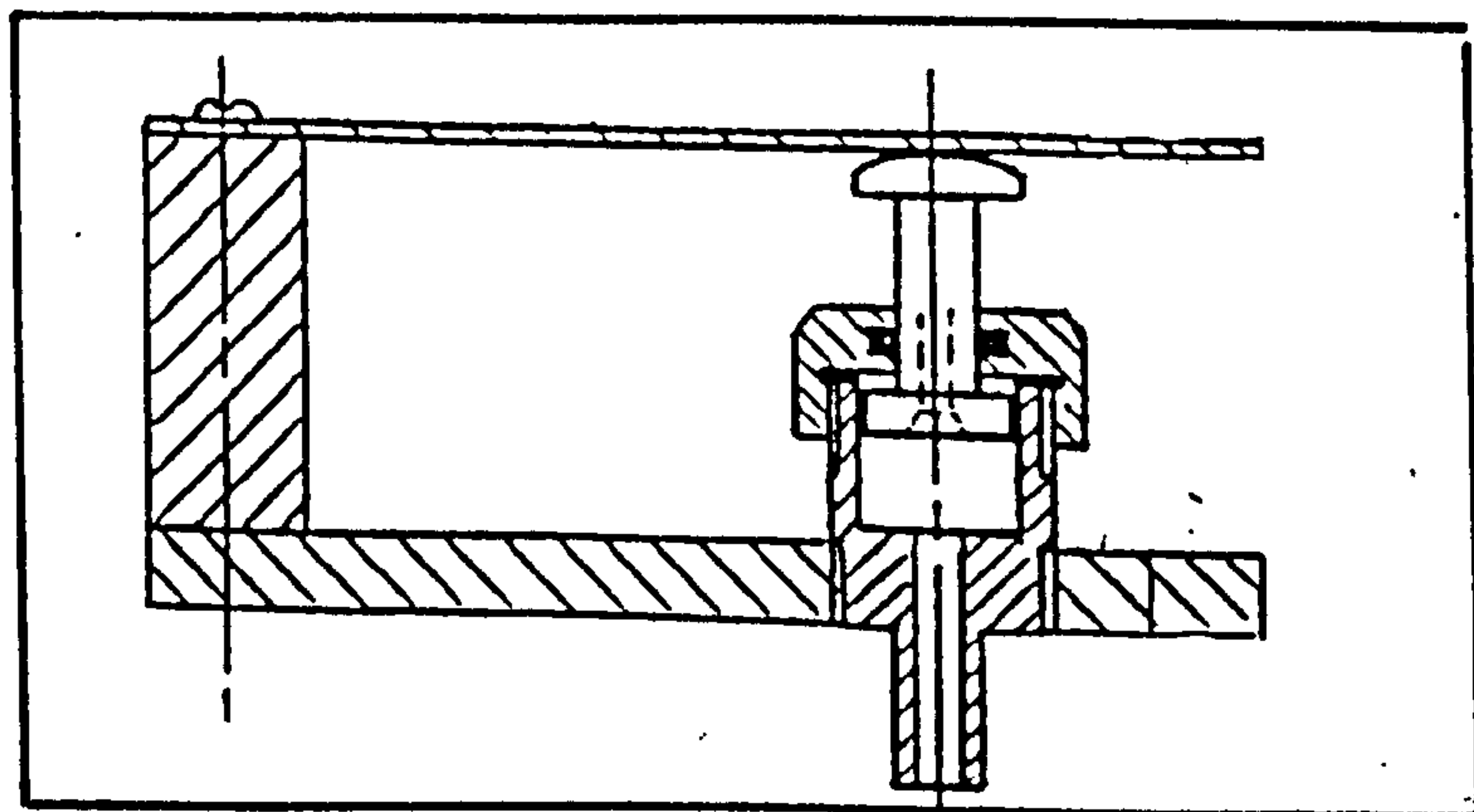


Figure 27 Main body of Prototype 3 with Piston Inserted
(A draft drawing of prototype 3 available in Appendix 1)

The main body of Prototype 3 was enlarged at the block on the left hand side, to give a greater distance between the top and bottom plates. A hole was then drilled and tapped, the sleeve of the piston was then threaded and screwed into the hole made for it.

The piston was also made out of stainless steel. It was machined to the following specification as shown in Figure 28

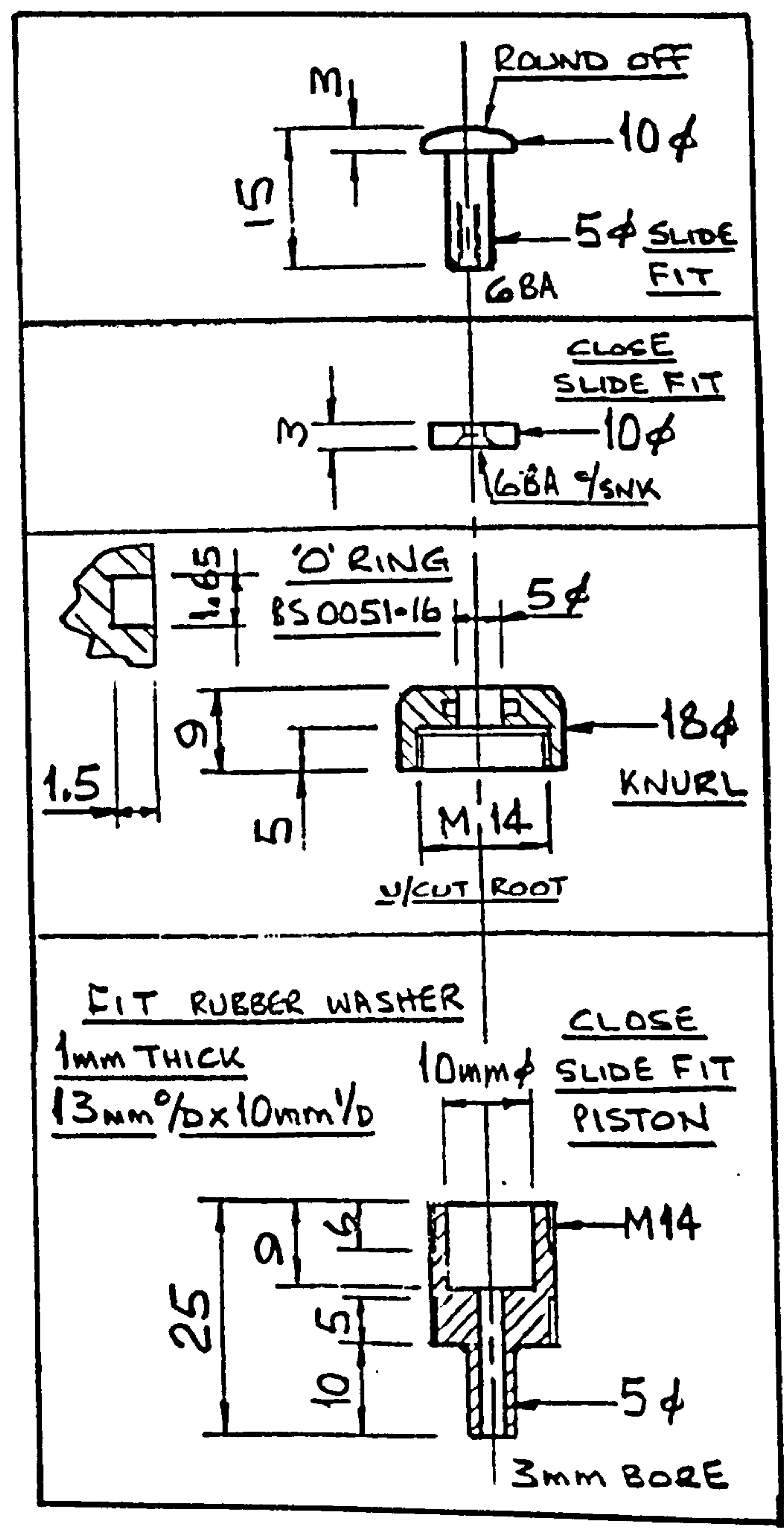


Figure 28 Specifications for Machining of Piston

When assembled and inserted into Prototype 3 it was realised that when pressure was applied to the top plate from the piston while attached to the small electrical compressor the top plate could over-extend. Therefore a small guard was required to stop this from happening.

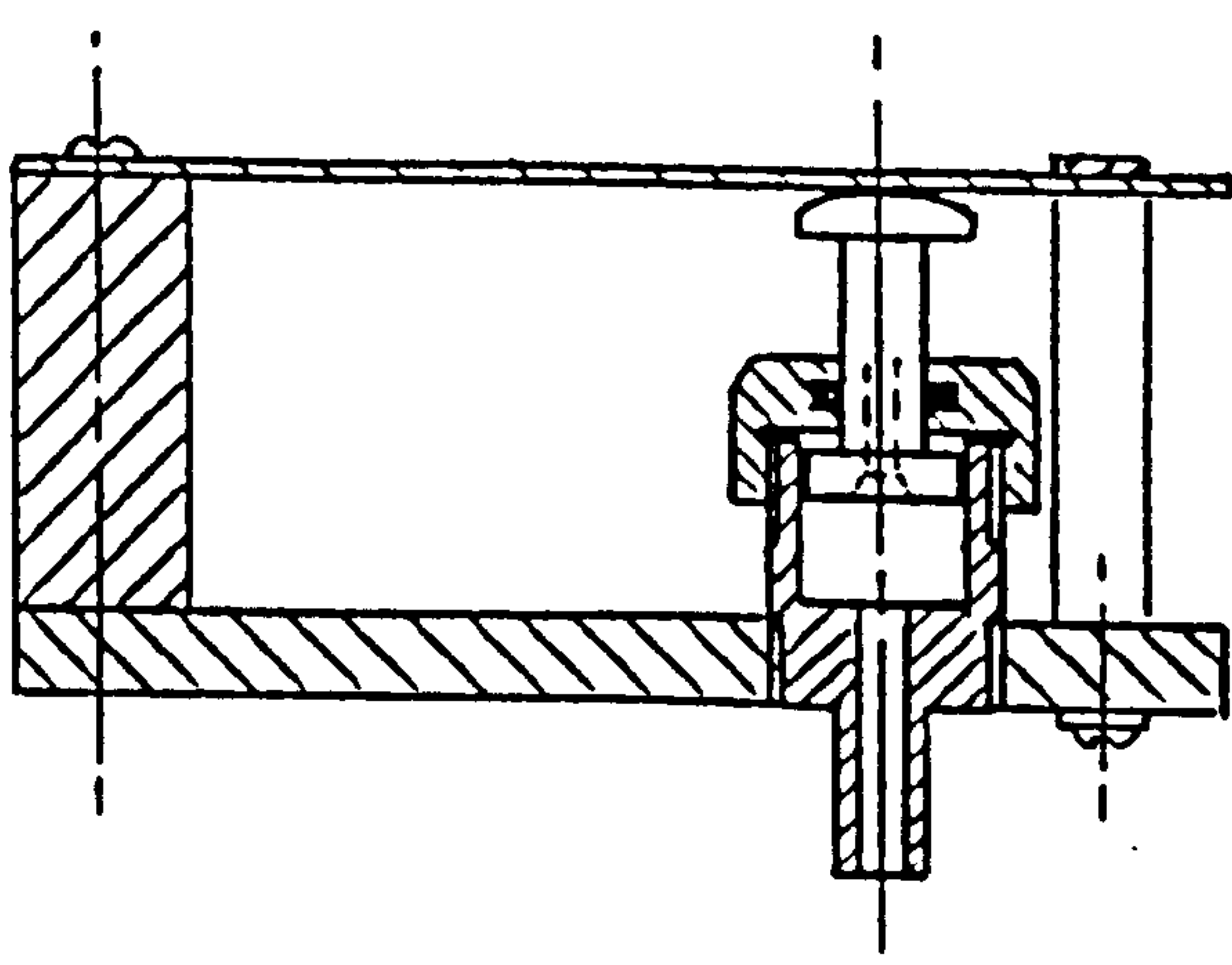


Figure 29 Main body of Prototype 3 with Guard Attached

Two main problems now remained to be solved. When air pressure was applied to the piston, it leaked. To eliminate this silicone grease was smeared around the chamber. A small piece of rubber was then slipped onto the shaft of the piston to act as a piston ring. Plumbers tape (PTFE) was then wrapped around the thread of the outer sleeve of the piston to stop any leaks from that point. Finally a special screwdriver was made to tighten the existing screw thus expanding the rubber piston ring further.

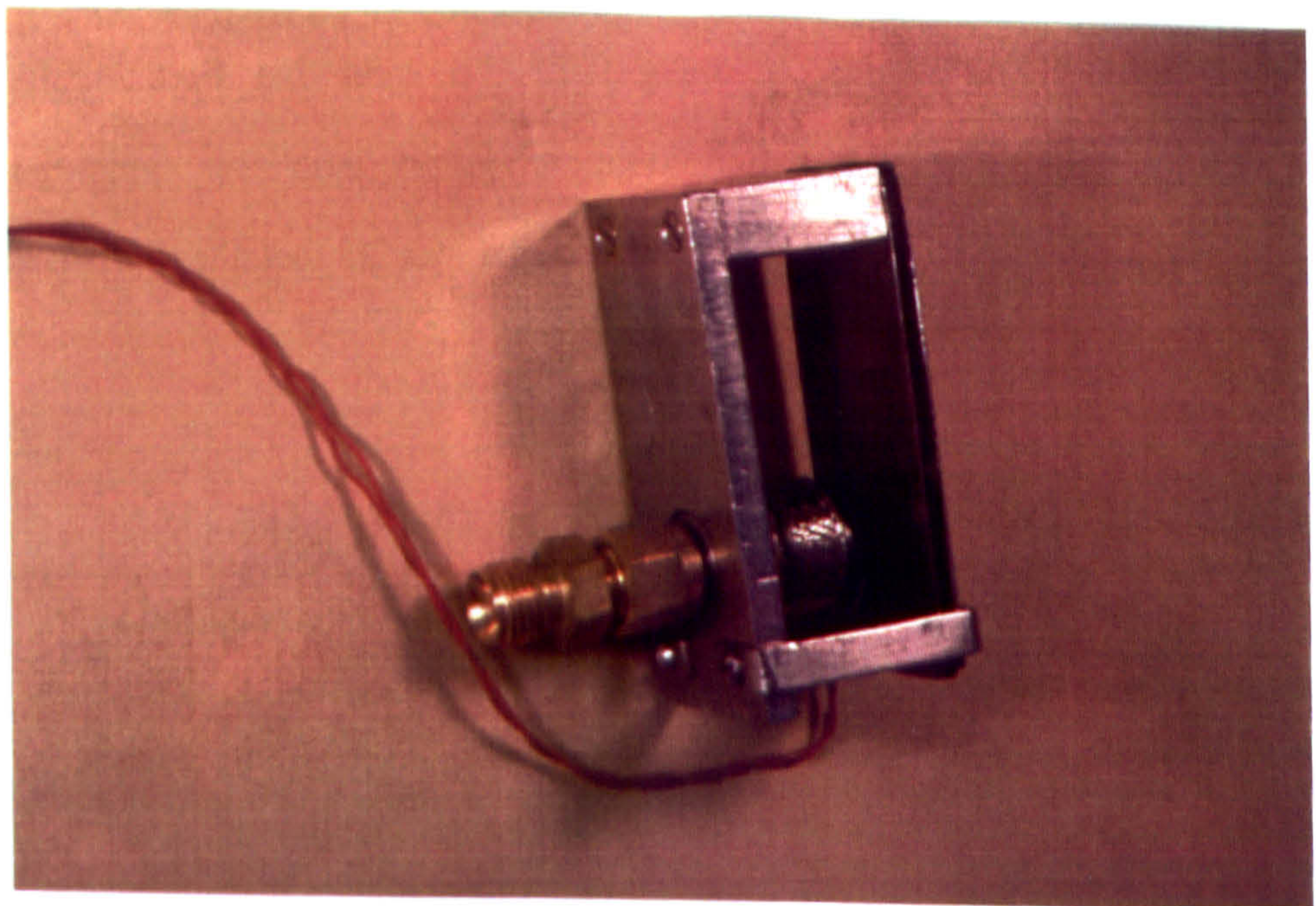
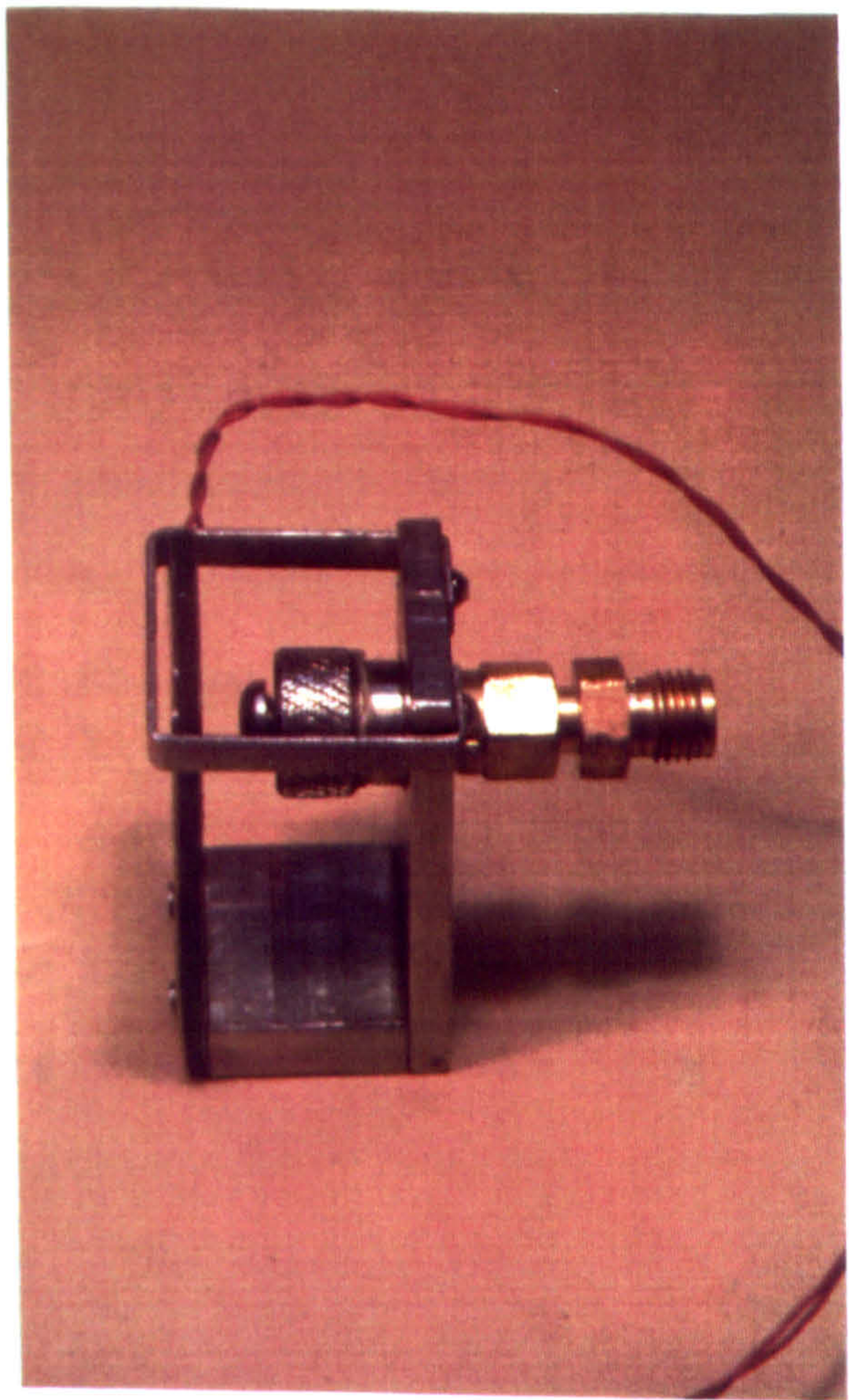


Figure 30 Pictures of pressure sensor
Prototype 4 with the piston on the
connection of strain gauge

The second problem that remained to be solved was as follows. When pressure was applied to the strain measuring area, due to the location of the strain gauge, the subject's thumb would come into direct contact with it. Consequently the accuracy of the readings would be questionable.

Therefore it was decided to protect the strain gauge. This was done by cutting out the shape of the strain gauge from a piece of 1mm thick rubber, that was the same dimensions as the top plate. The strain gauge was then inserted into the space cut out for it and attached, see Chapter 3, section 3.6. Then a new piece of stainless steel was cut to the same shape as the bottom plate. This was then attached on top of the piece of rubber which in turn was on top of the bottom plate to form a sandwich. This is shown in the diagram below:

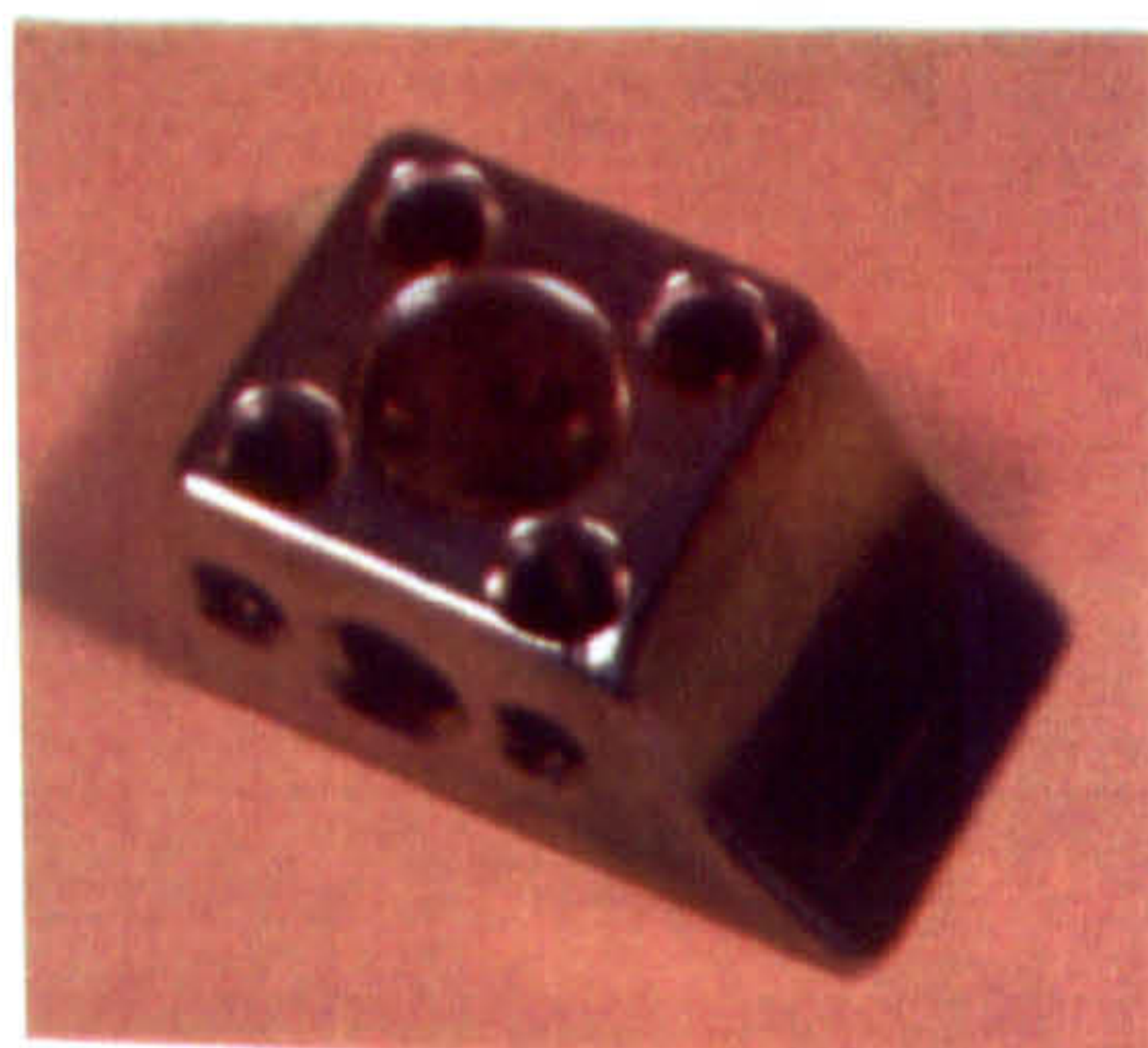


Figure 31 Shows piece of stainless steel used as a pressure point

From testing we noticed that different subjects were moving their thumb on the top of the measuring area. Some pressing with the side of their thumb, others with the full surface of the thumb. This was affecting our results. Therefore a small piece of stainless steel was machined to the following shape.

It was then drilled at the various points shown to reduce its weight, thus it would not affect the subject's natural pressure on the strain measuring area.

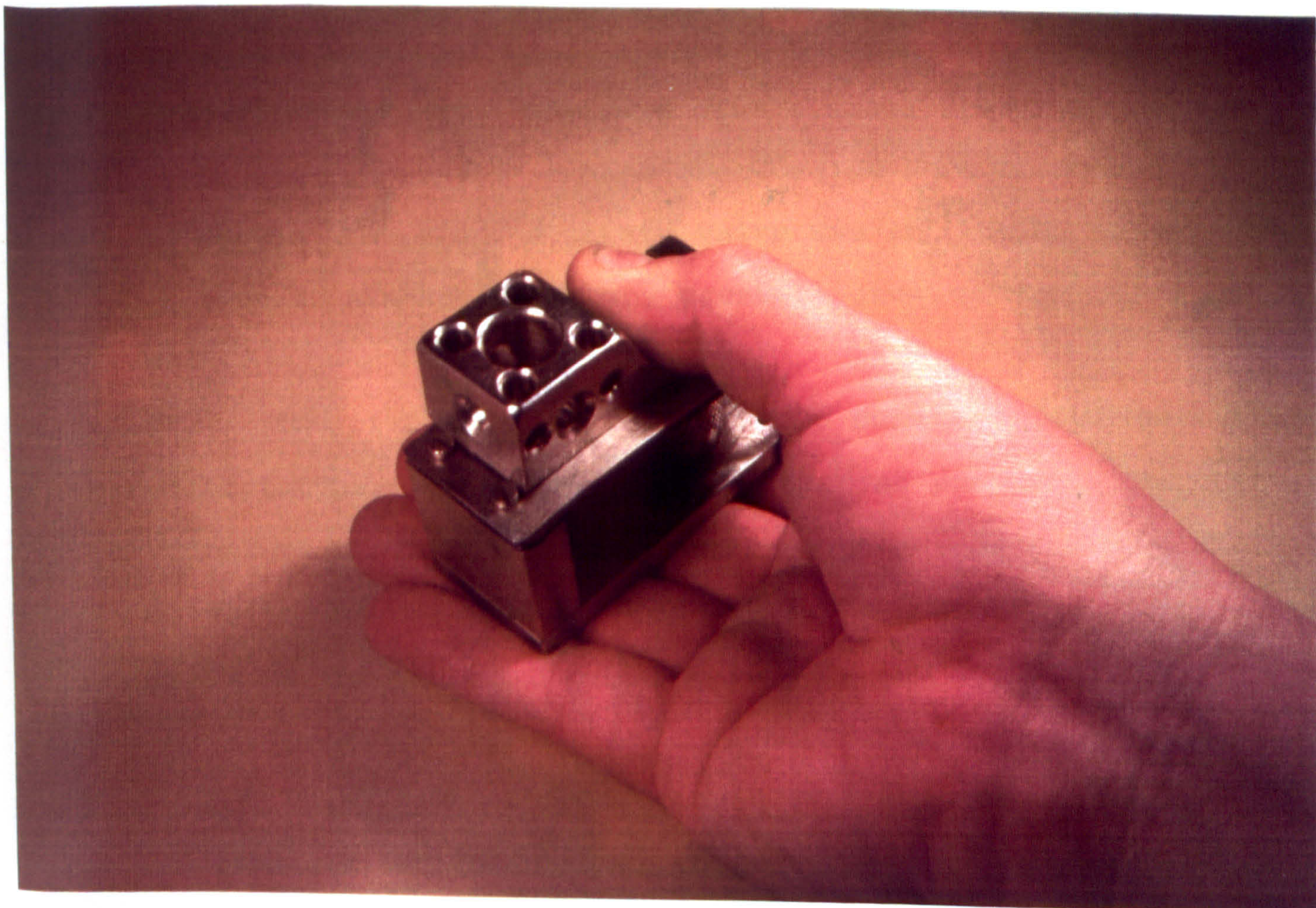


Figure 32 Picture of a patient using final version of the pressure sensor prototype 4

Once these modifications were completed the pressure sensor was tested under water for leaks. Once it was found to be in perfect working order the new design was referred to as Prototype 4 (see Appendix 1).

4.2 Air Pressure Regulation

To place the piston under load, a small electrical compressor was employed. It ran off a 12 volt dc input at 5 amps, and could produce pressures up to 200 pounds per square inch (p.s.i.). A safety point was noted, dealing with high pressure over a small area ran the risk of the compressor perhaps overloading some component in the system, therefore a safety valve was introduced which would vent to atmosphere at any pressure greater than 200 p.s.i.

The piston had to be kept at a constant pressure whilst Prototype 4 was being used for testing purposes. So, to ensure that air did not travel back towards the compressor whilst under pressure from the subject finger a one-way valve was fitted, thus stopping any backpressure.

Regulation of pressure was very important. High pressure settings had to be provided for strong people and lower pressure settings for people with less strength. Therefore the pressure had to be variable, from 50 p.s.i. up to 200 p.s.i. To do this a relief valve was fitted between the one-way valve and the pressure gauge. This

enabled the piston to be fully loaded and then the pressure would be dropped to match the subject's strength. The pressure gauge enabled us to record precisely the pressure the subject required to load the piston. 1/4" pipe was used to connect all the components together, rate at 250 p.s.i. A reducing union connected the pipe to the 5/16" fitting on the piston and an increasing union to connect to the compressor. All the parts used in this section are listed in the component list (page 132).

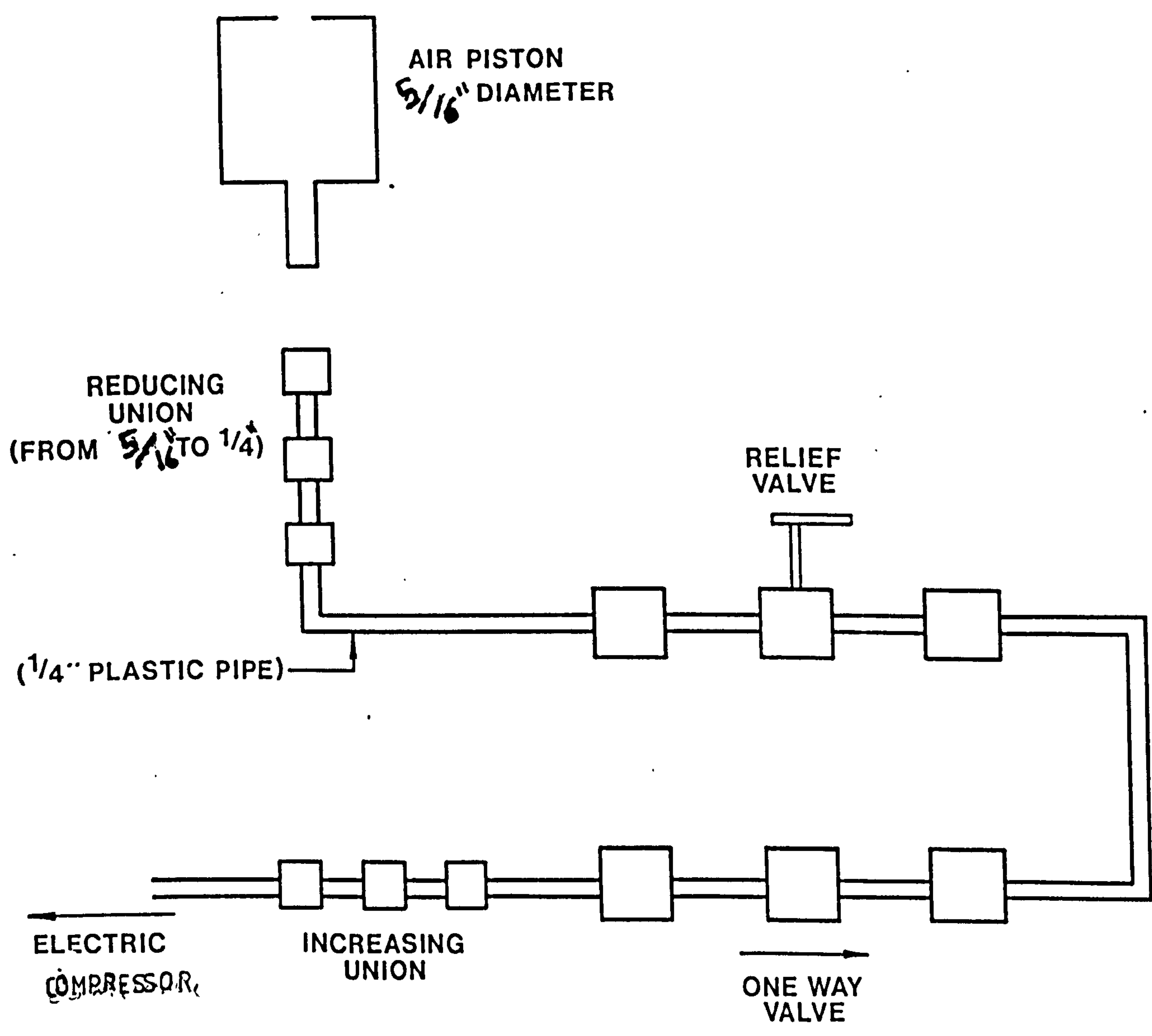
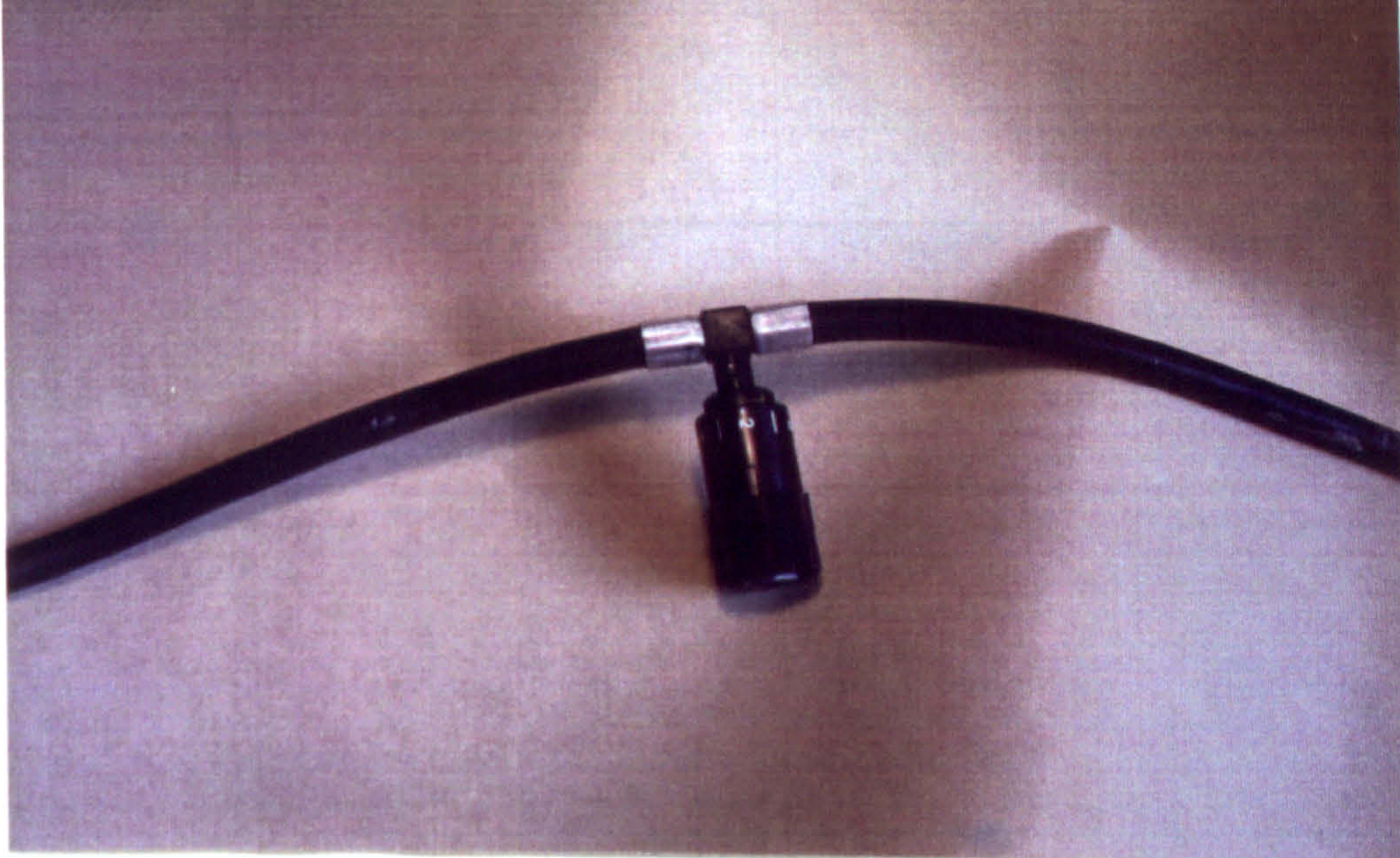


Figure 33 Showing the connection of the electrical
compressor to the piston
(see also Figure 34)



Shows a picture of a safety valve used with the electrical compressor.

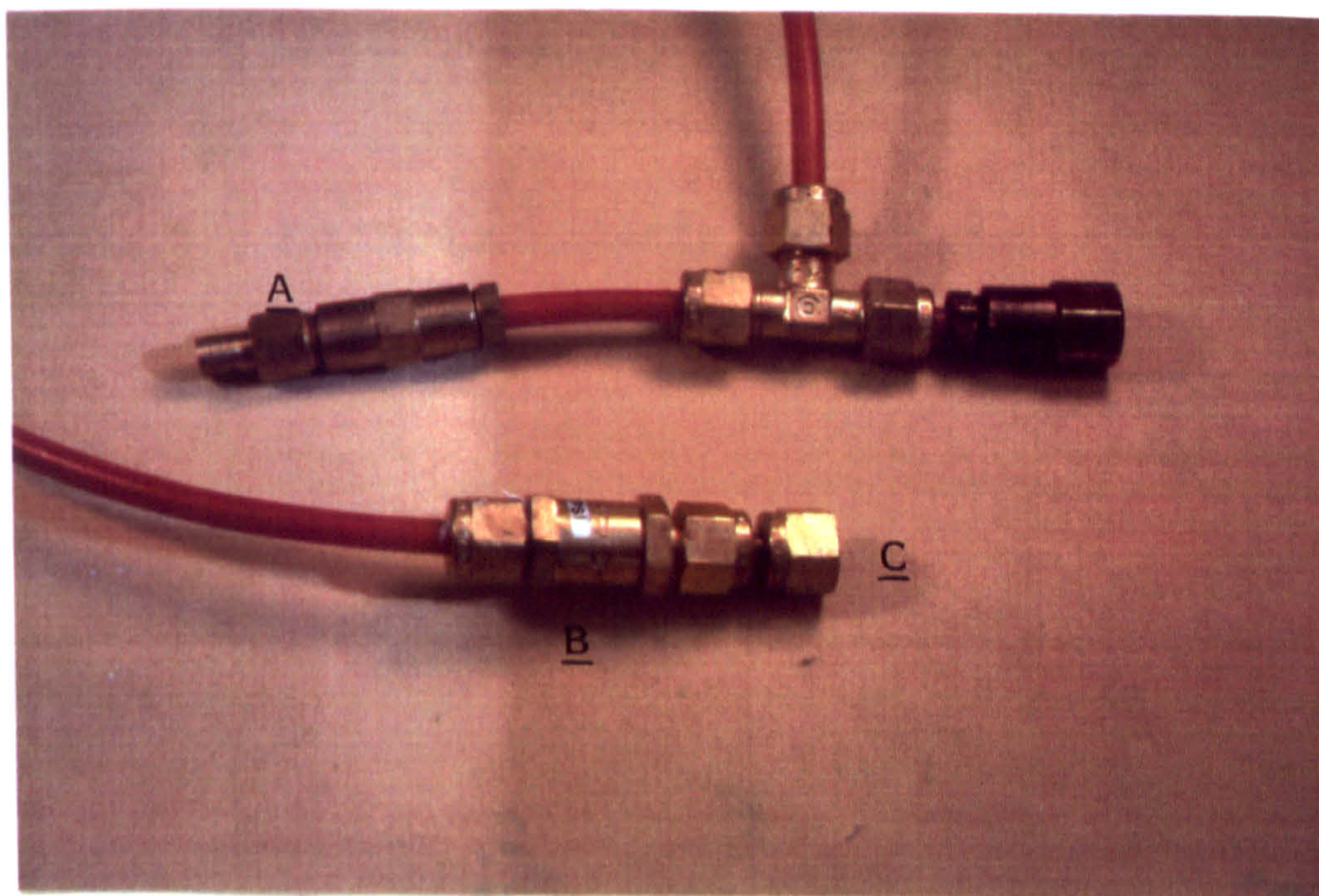


Figure 34 A - Reducing Union
 B - One-Way Valve
 C - Enlarging Union

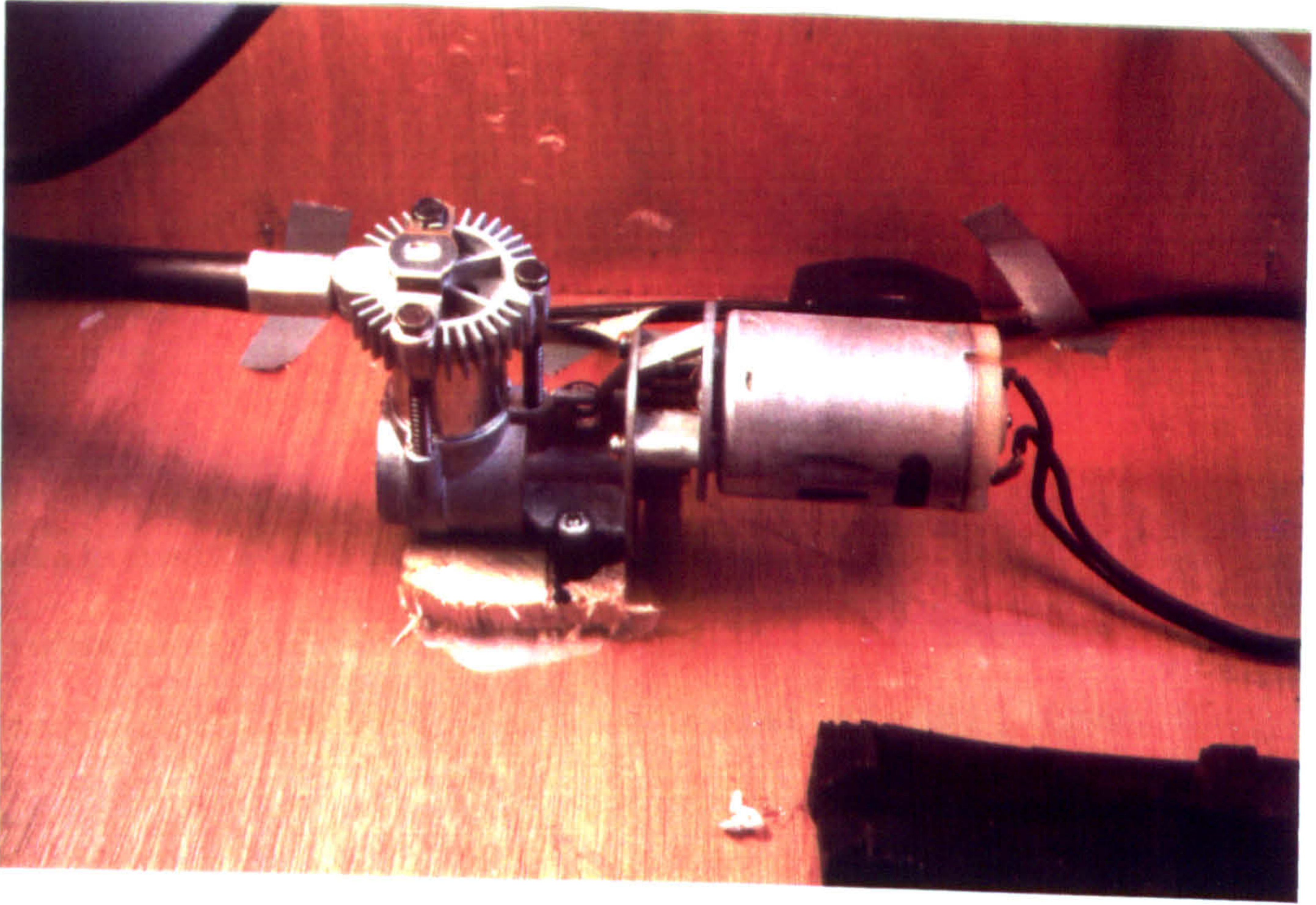


Figure 35 Picture of Electrical Compressor

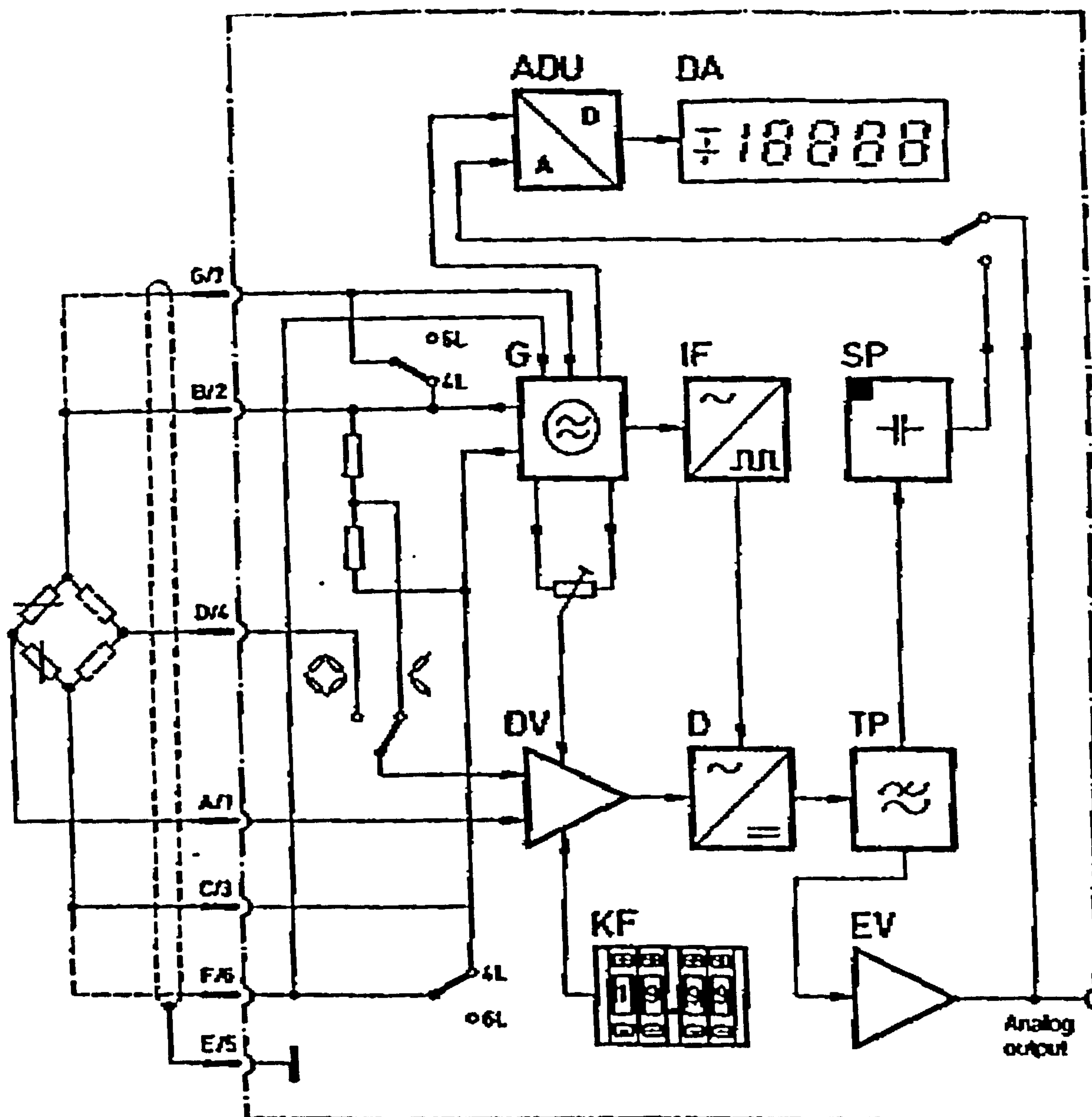
4.3 Electrical Development

This section is concerned with the electrical development of the system in particular the conversion of mechanical power into an electrical signal, then the amplification of the signal, conversion of the signal A/D, the processing of the signal through the microprocessor (if it was needed) and the display of the signal.

4.3.1 The Strain Gauge

The strain gauge used was manufactured by HBM of Oxford. The gauge had a 320 Ω value. To obtain the best results from the strain gauge it was important to clean it and the surface it was to be attached to thoroughly (see Chapter 3, section 3.4)

A previously borrowed specialised strain gauge amplifier from HBM (a very expensive amplifier costing over £1,500 thus proving far too expensive for this research) was connected directly to the strain gauge, as shown in figure 36. To gain the best readings the strain gauge was tested at various points along the strain measuring surface, when the best results were obtained it was permanently attached to that point.

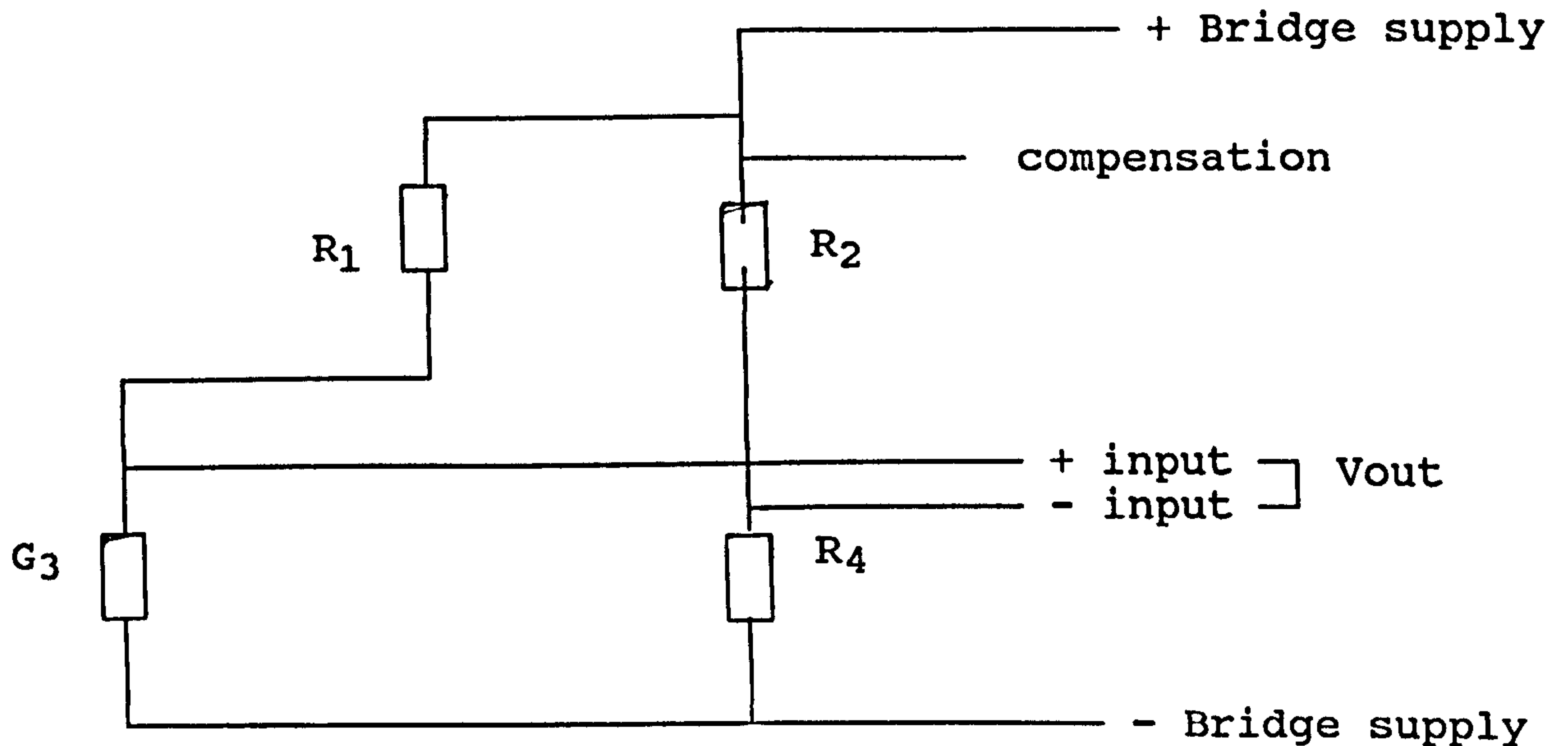


ADU = Analog-to-digital converter, DA = Digital indicator, G = Generator, IF = Pulse shaper, SP = Peak value store, DV = Differential amplifier, D = Demodulator, TP = Low pass filter, KF = Gauge factor switch, EV = Output amplifier

Figure 36 Shows HBM amplifier connected to Wheatstone Bridge

4.3.2. Wheatstone Bridge

The schematic diagram below shows the layout of a quarter bridge, a variation of the Wheatstone Bridge for feeding into an instrumentation amplifier.



G_3 active gauge
 R_1, R_2 resistors
 R_4 multi-turn potentiometer

Figure 37 Shows $\frac{1}{4}$ Wheatstone Bridge

Where R_1 has a value of 33Ω , G_3 is an active gauge 320Ω , R_2 has a value of $1k \Omega$ and finally R_4 is a $10K \Omega$ multi-turn potentiometer. The output from the bridge now goes directly into an instrumentation amplifier. (All the values were calculated using formulae from Chapter 3, section 3.7.)

4.3.3 Instrumentation Amplifier

In this section, specialised amplifiers were used, these are called instrumentation amplifiers. These amplifiers are useful in signal conditioning applications where a precise gain is required in the presence of common mode voltages and other interfering signals.

The different configurations of the amplifier which have been used in this research will be examined and reasons for the choice for the final system will be provided.

i Amplifier 1

In the first design configuration (see figure 38), the amplifier gives an output given by the following equation:

$$E_o = \frac{(A) (V) (\Delta R/R)}{4(1 + \Delta R/R)} - A V_{os}$$

Where R and Vos equal transducer variation and amplifier input offset voltage respectively. As R appears in both the numerator and the denominator of the first term this circuit developed non-linear output response, but making R small- so that its effect in the denominator is negligible - minimises non-linearity error. By doing so it also reduces the output signal level, making Vos term error more significant.

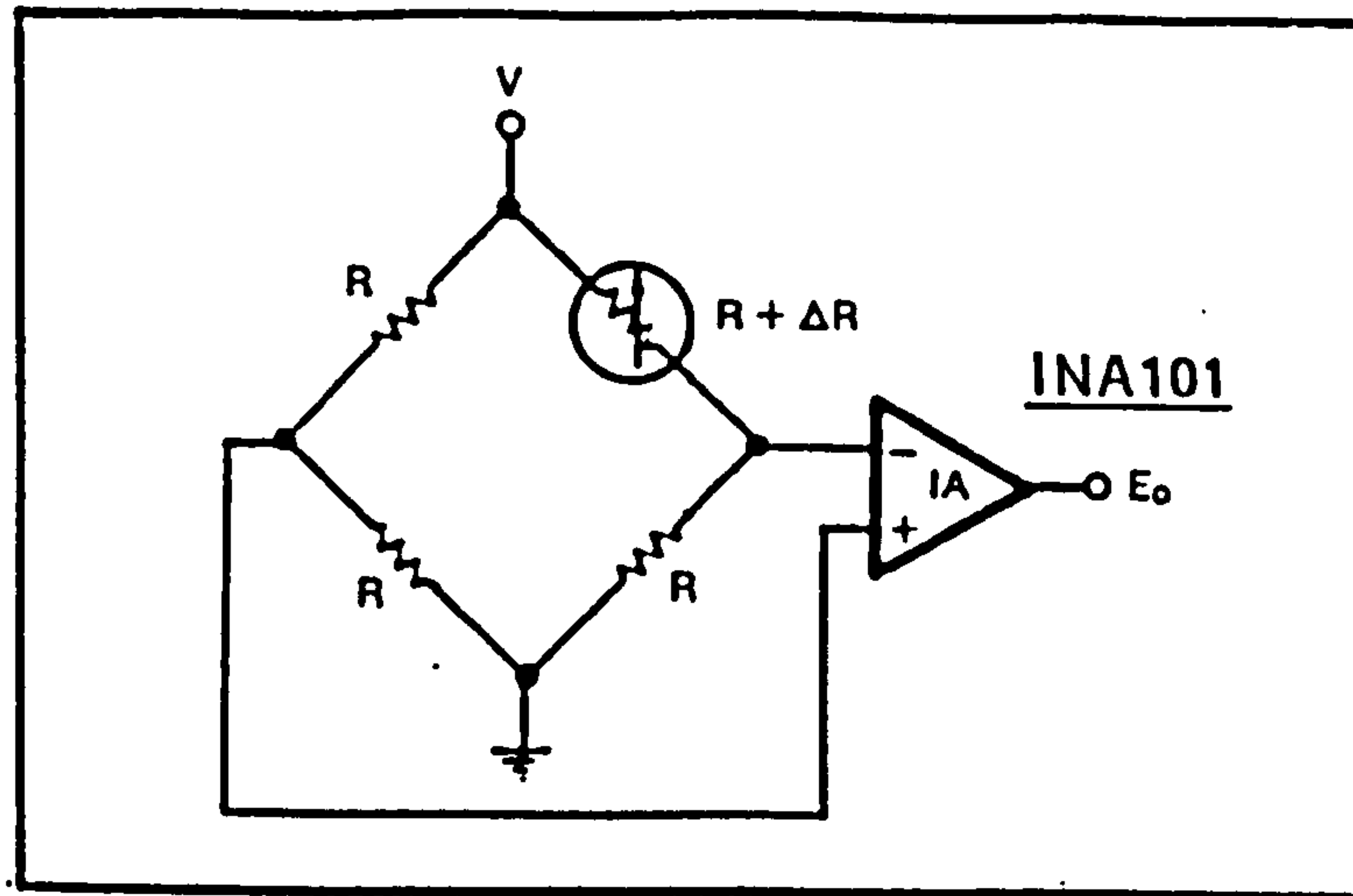


Figure 38 Shows configuration of amplifier 1
connected to a Wheatstone Bridge
Data Sheet of instrumentation amplifier
INA101

ii Amplifier 2

To develop a signal proportional to R , instrumentation amplifiers output was developed by feeding the signal back through the op amp as shown in figure 39:

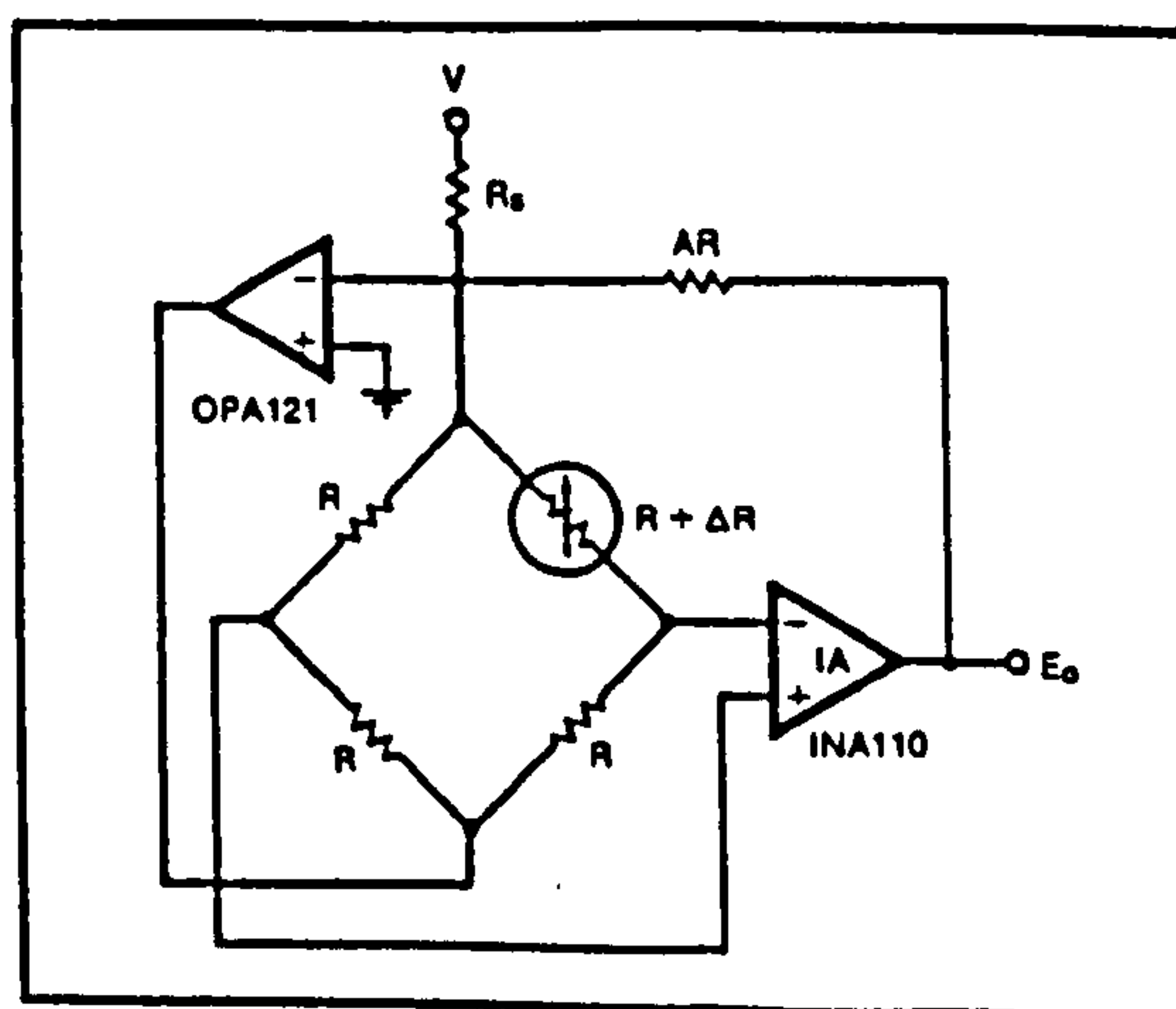


Figure 39 Shows instrumentation amplifier 2
connection to Wheatstone Bridge
(OPA121 is a normal amplification)

In the above design the op amp controls the voltage at the point of the bridge that is normally grounded. This addition yields a circuit response given by the following equation:

$$E_o = \frac{A}{4} \frac{V \Delta R}{R} - A V_{os}$$

In this expression if the op amp circuitry has a gain of $-2/A$, where A equals the instrumentation amplifier gain, non-linearity cancellation is complete. Unfortunately perfect gain linearity could not be achieved. Thus, this arrangement was not used either.

iii Amplifier 3

Another design for achieving error correction is feedback modulation of a bias current. The op amp in figure 40 forces a constant current to flow in a bias resistor (R_s). Adding a signal derived from the instrumentation amplifiers output develops an output E_o as follows:

$$E_o = \frac{A}{4} \frac{V \Delta R}{R_s} - A V_{os}$$

In the following circuit the feedback resistance determines the linearisation accuracy. Unfortunately a reference current source suitable for this approach was not as readily available as the voltage equivalent reference source.

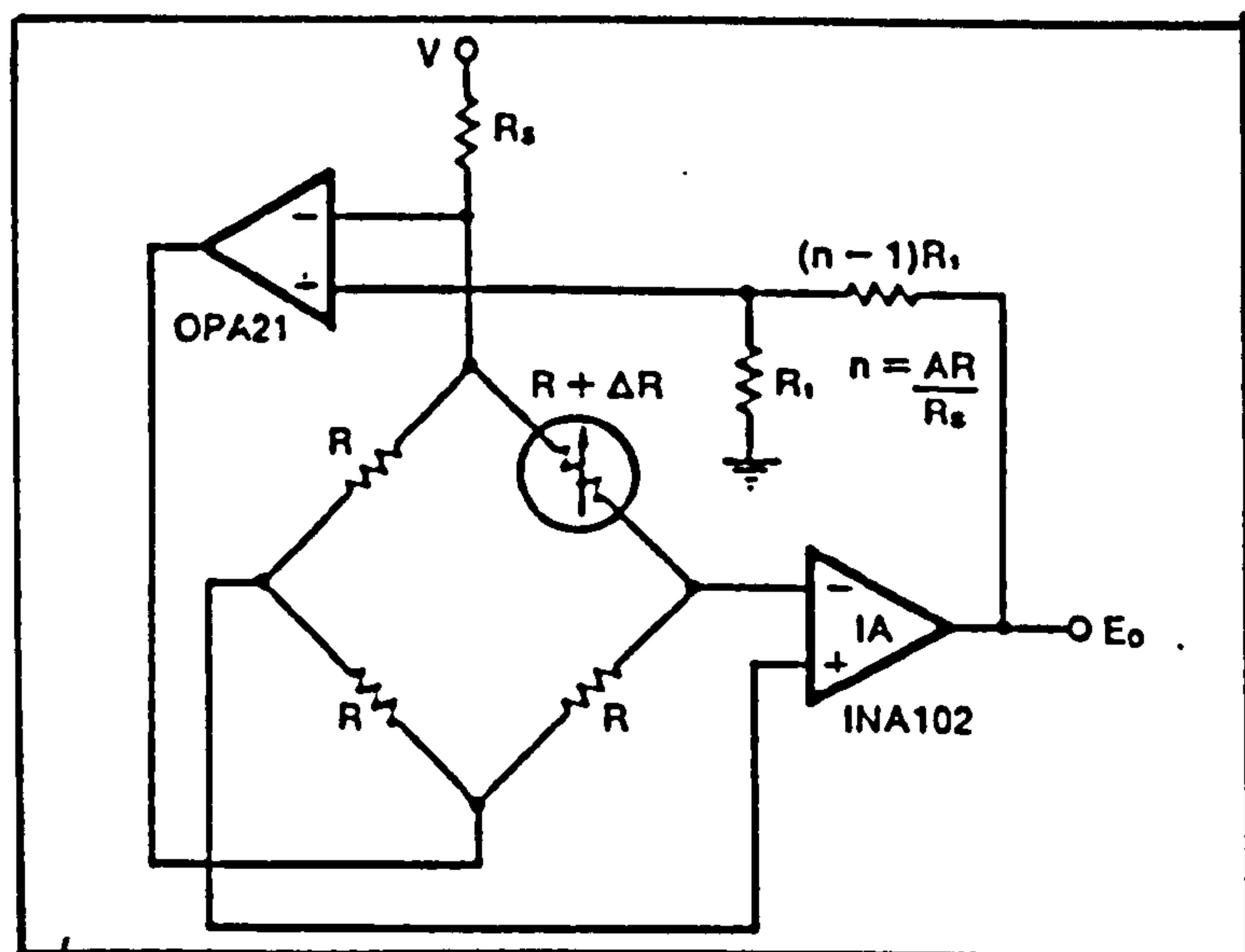


Figure 40 Shows the connection of instrumentation amplifier connected to Wheatstone Bridge

IV "Radio-Spares" Amplifier

This amplifier overcame the problem of common-mode-rejection by removing the common-mode voltages. This was achieved by controlling the negative bridge supply voltage in such a manner that the voltage at the negative input terminal was always zero. Thus for a symmetrical bridge, a negative bridge supply was generated equal and opposite to the bridge supply, hence zero common mode voltage. The advantages of such a system are:

1. No floating power supply is required.
2. Bridge supply easily varied with remote control if necessary.

3. 5-wire remote sense system.
4. Freedom from common-mode effects, numerous configurations can be assembled.
5. Low noise.
6. High operating speed, (at low gain).

+ Bridge Voltage	1	24	+ V_s
N/C	2	23	N/C
Compensation	3	22	- V_s
N/C	4	21	N/C
N/C	5	20	Bridge Ref Input
+ Input	6	19	N/C
N/C	7	18	Feedback
N/C	8	17	N/C
N/C	9	16	Output
- Input	10	15	N/C
N/C	11	14	N/C
- Bridge Voltage	12	13	Zero Adjust

Top view

Figure 41 Pin Connection for Integrated Circuit

Circuit diagram for RS Amplifier

All the components were marked on an RS P.C.B. the values of each of the components were provided by RS data sheet (as shown in the Appendix 3).

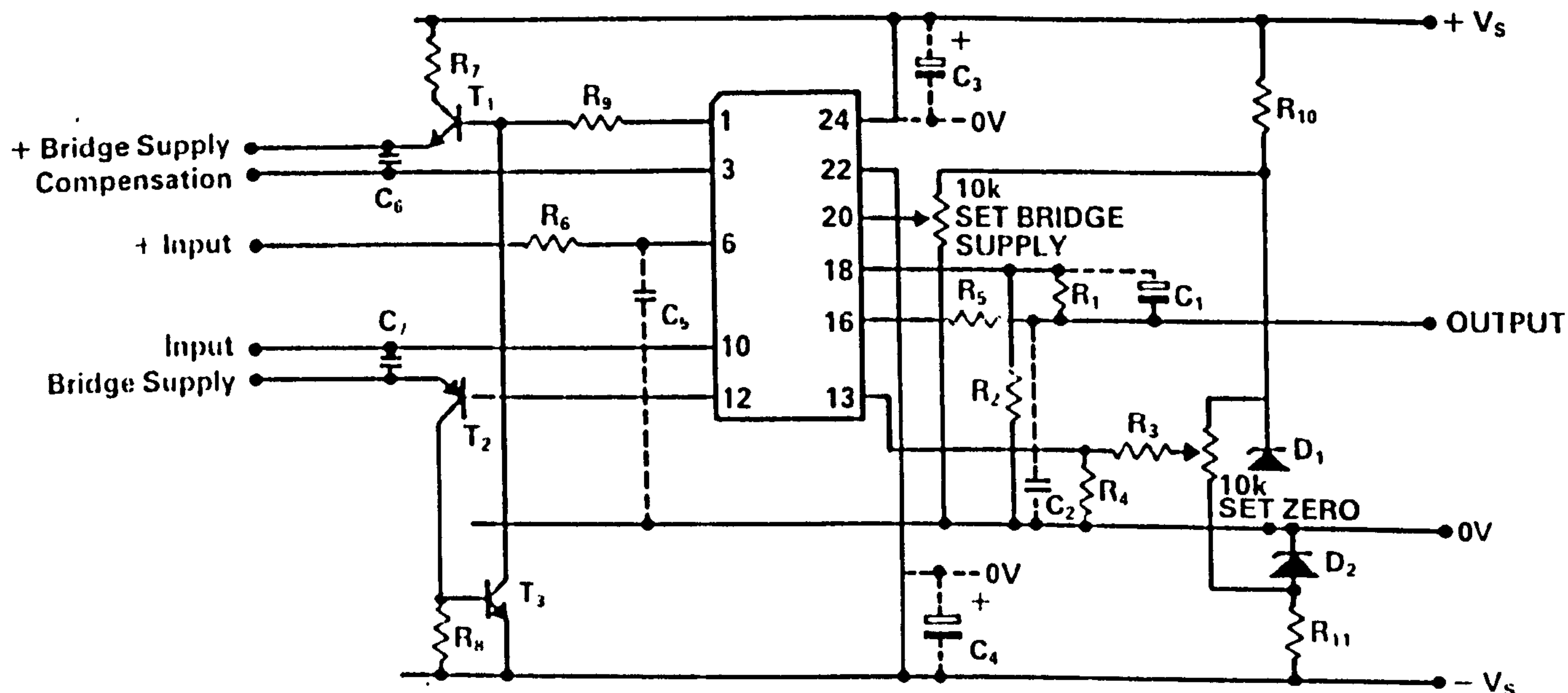


Figure 42 Shows the connection of RS amplifier

The values of R_1 & R_2 can be adjusted to increase or decrease the gain as shown below.

$$\text{Gain} = 1 + \frac{R_1}{R_2}$$

$$R_1 = 1 \text{ M } \Omega$$

$$R_2 = 1 \text{ K } \Omega$$

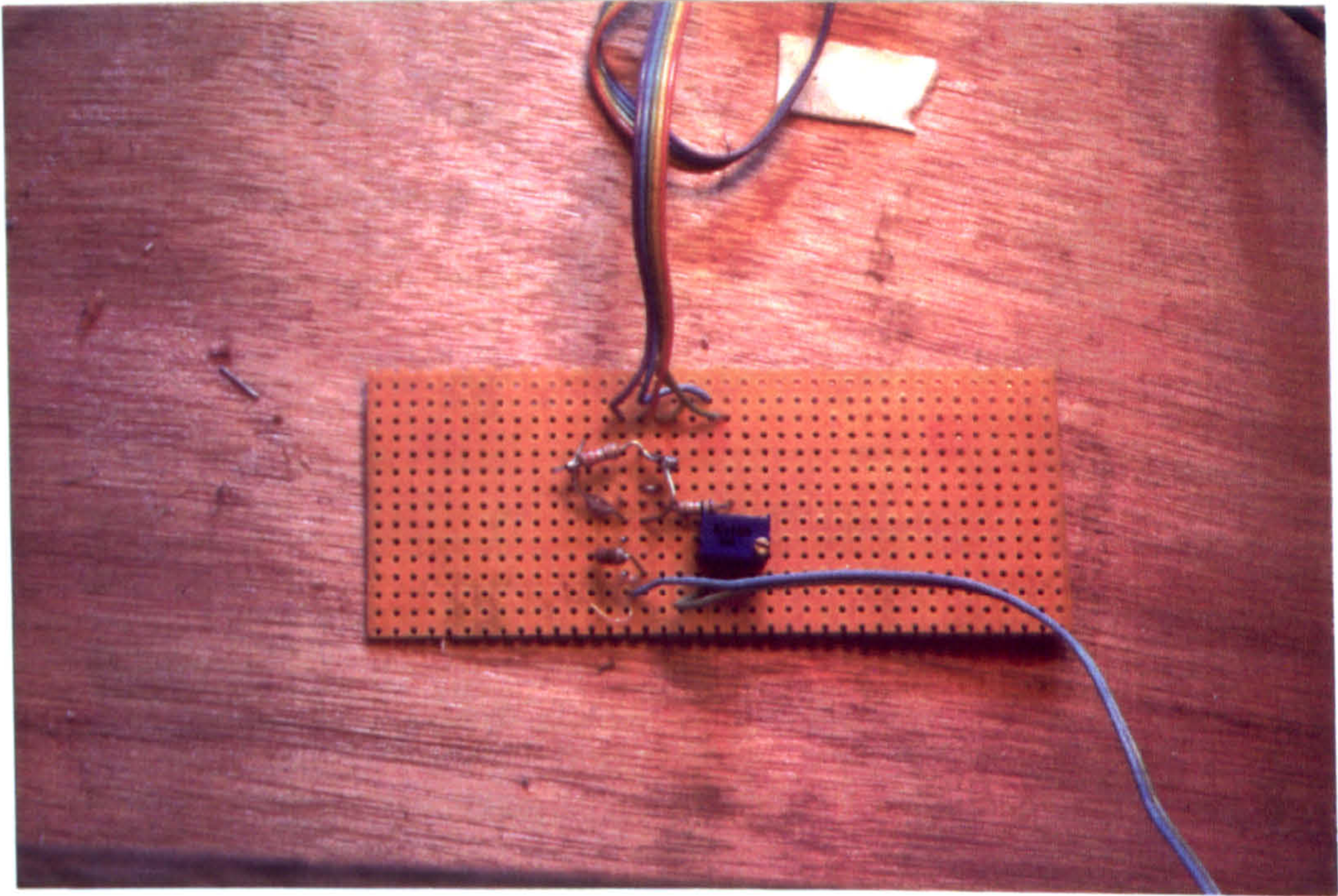


Figure 43 Picture of Wheatstone Bridge

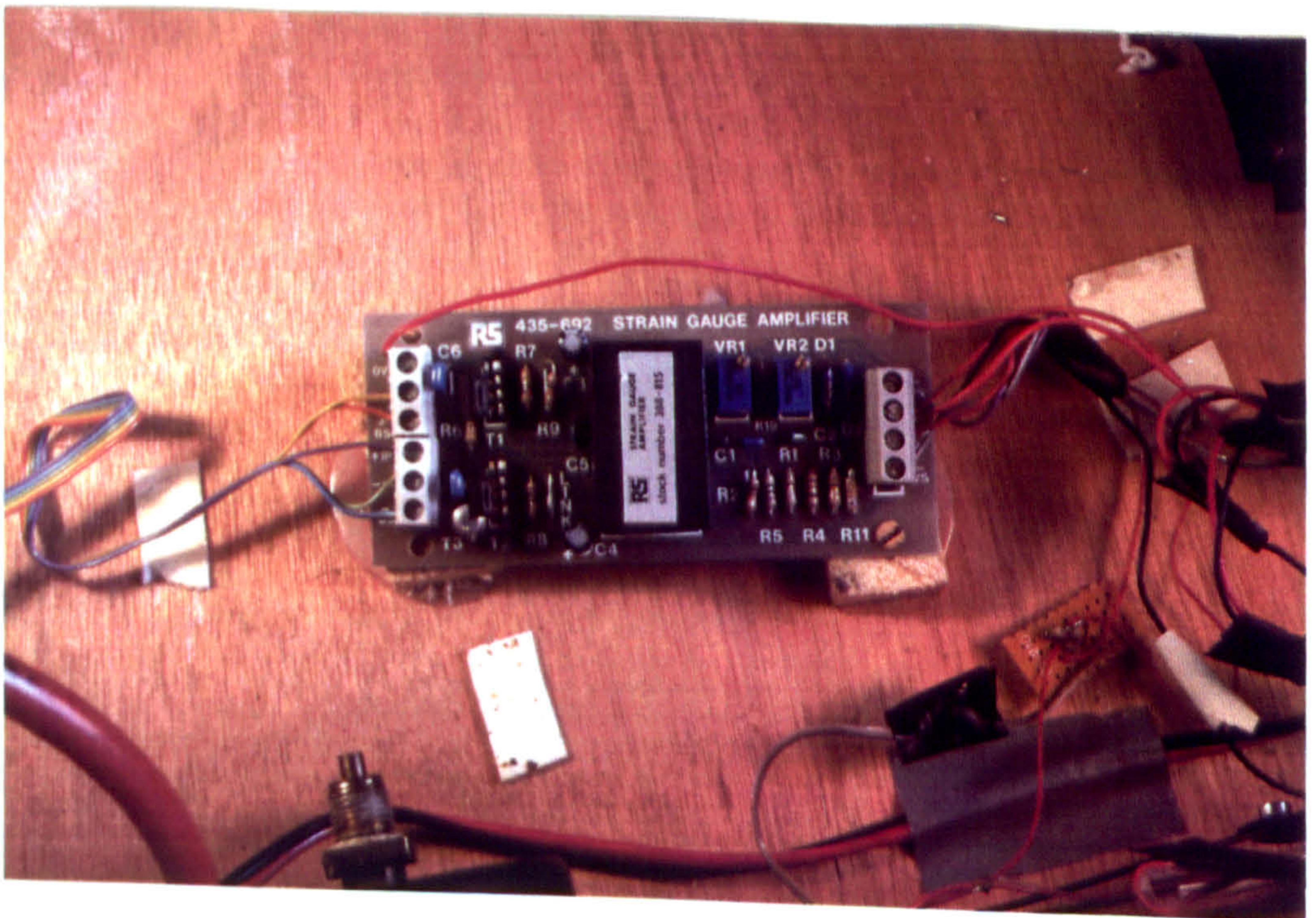


Figure 44 Shows a picture of RS Strain Gauge Amplifier

4.4 Analogue to Digital Convertor

An analogue to digital convertor was employed to convert the analogue signal from the strain gauge amplifier to a digital impulse to be fed directly into the microprocessor. The A/D convertor used was a Radio Spares 2N439. It has an 8-bit, successive approximation convertor and was used for its reliability and accuracy. The following diagram shows the pin-chip connections for the circuit. There is more technical information available on the A/D convertor in the appendix.

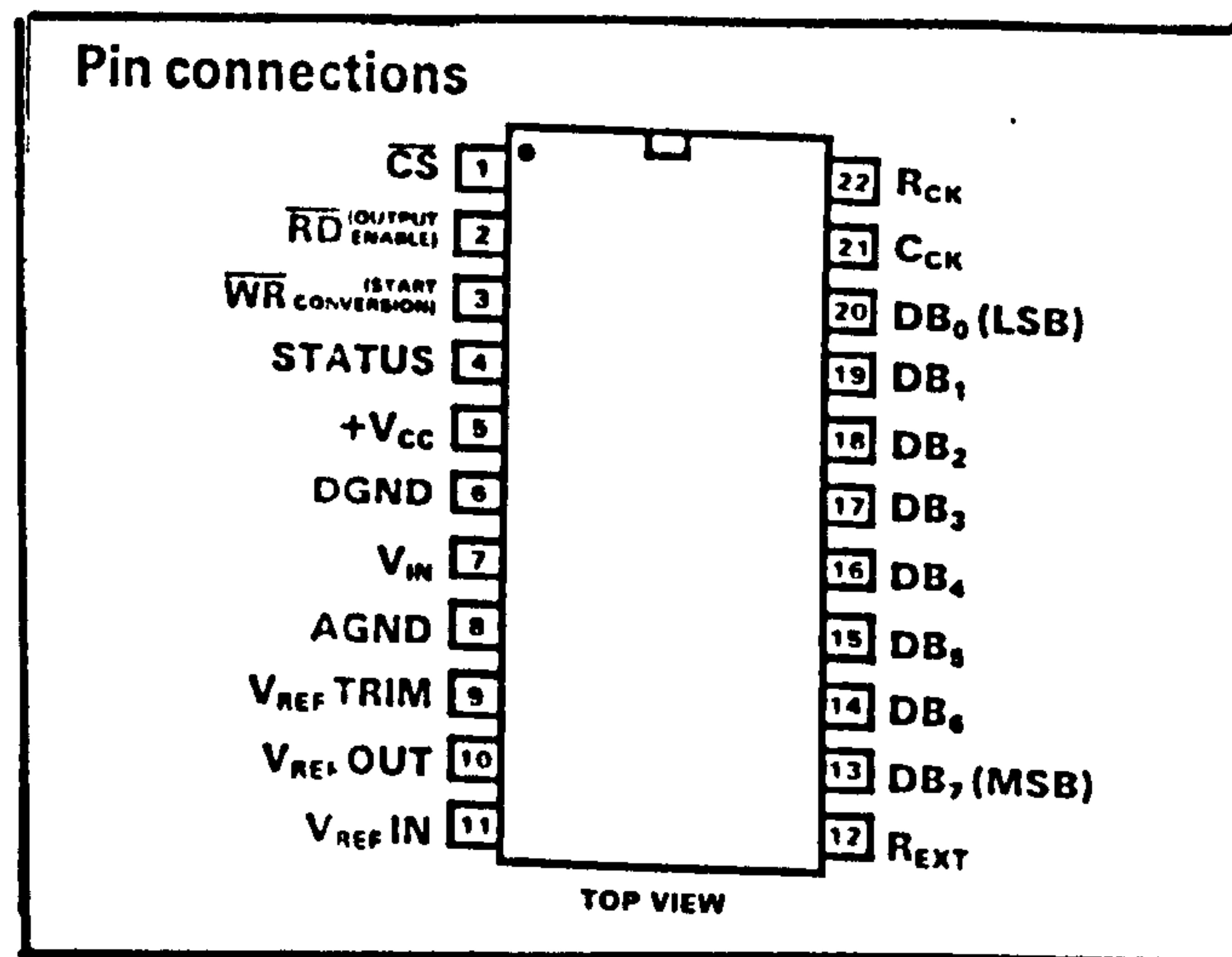


Figure 45 Pin-Chip Connection
A to D Converter

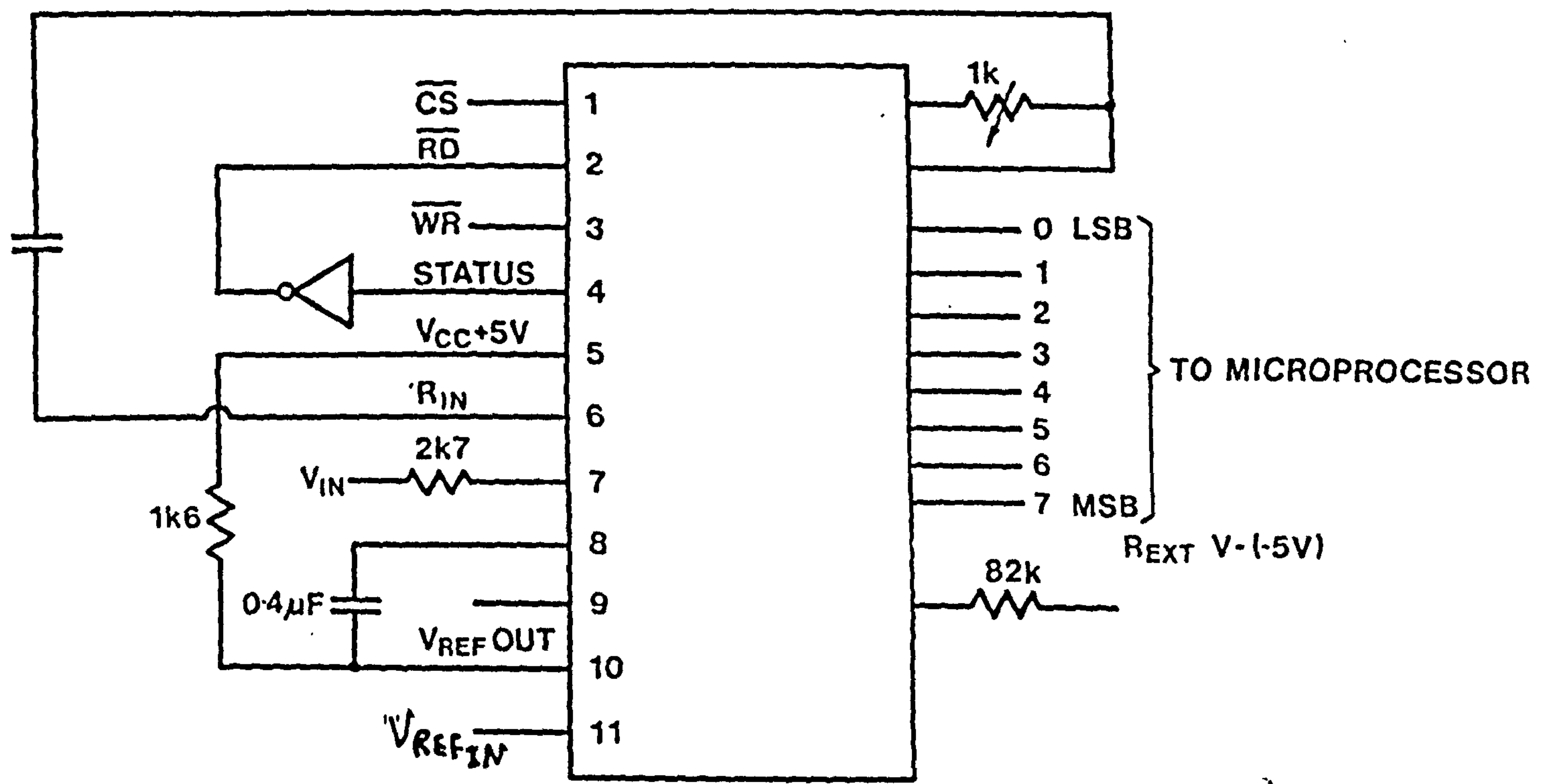


Figure 46 The external connection for a basic operation
for A/D Vin range: 0 to VREF. For more detail
see Data sheet in appendix 3

4.5

The Z80 Microprocessor

The Z80 processor has been around for many years, and is still proving invaluable in modern development. Practical applications of a Central Processing Unit require a module with a memory, input/output, a clock and facilities for further expansion. It has a memory of up to 8K, which is built up of 2K blocks. The first block of memory contains the operating system in ROM or EPROM. The second, third and fourth blocks can be made up of either ROM, usually associated with the operating of the processor or RAM, memory that can be programmed for a specific purpose. Static or CMOS 2K RAMS may also be fitted up to a total of 6K and a battery back up was also available. A keyboard/display decoding IC can be fitted thus allowing data input from a keyboard or other sensor.

Four decoding Input/Output select lines are available, and all data addresses and common control lines are buffered before being brought to the expansion edge connector.

In the final system it was not used because it had to be programmed for a specific printer, and it also increased the cost of the system to well over £1,500.

A simple printer was employed which was connected directly to the output of the strain gauge amplifier. This cost only £250, the data sheets for it are provided in the appendix.

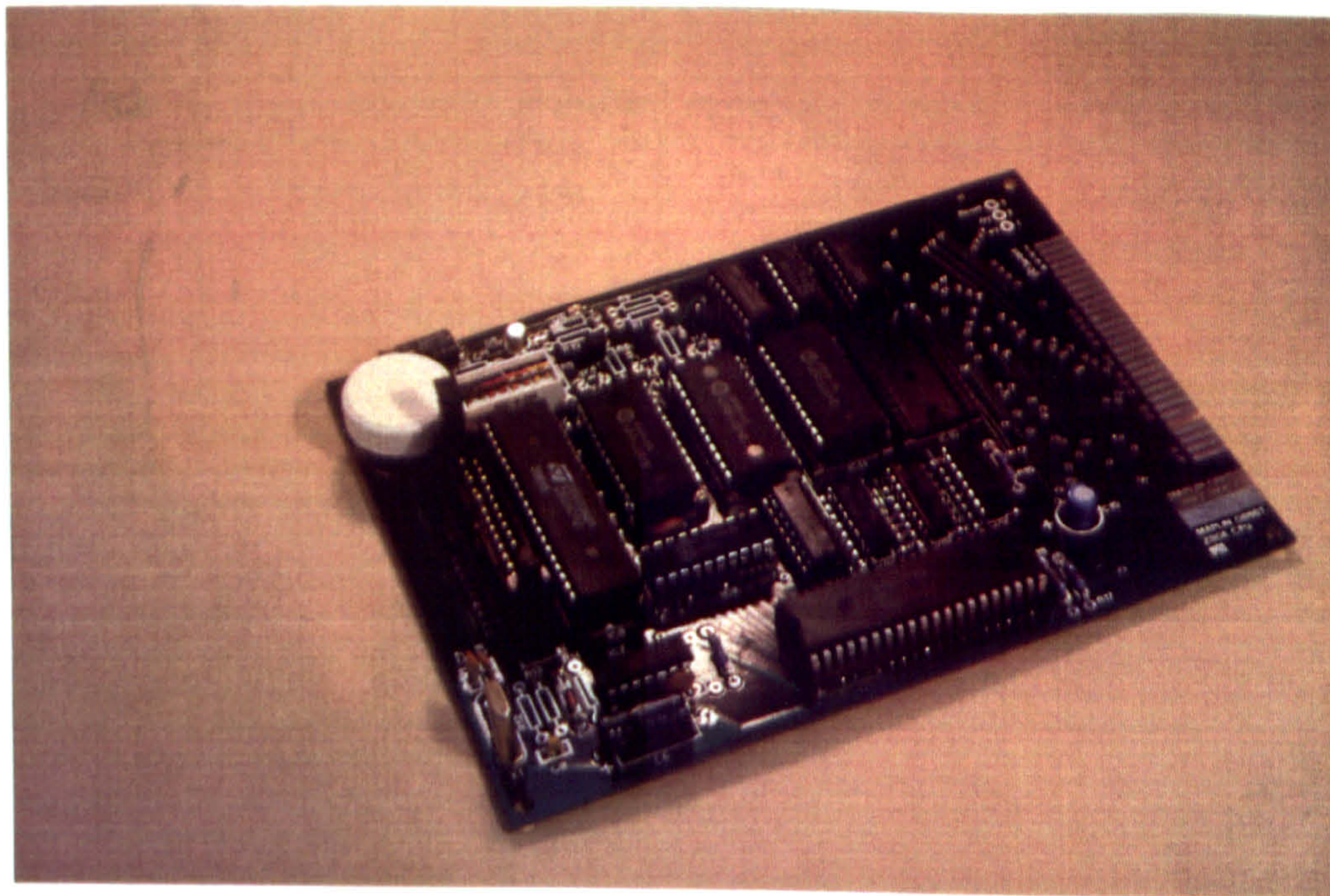


Figure 48 Picture of Z80 Processor

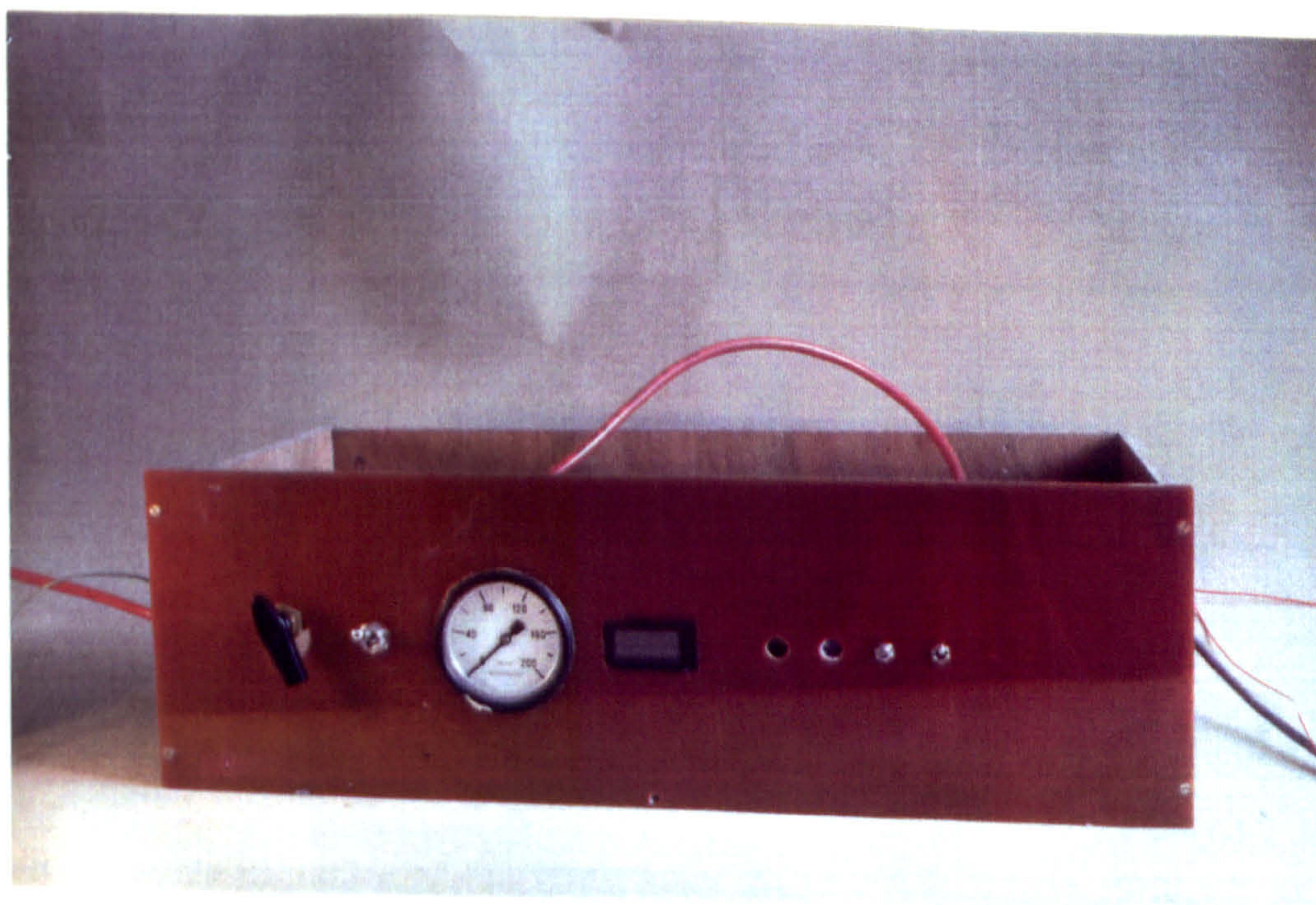
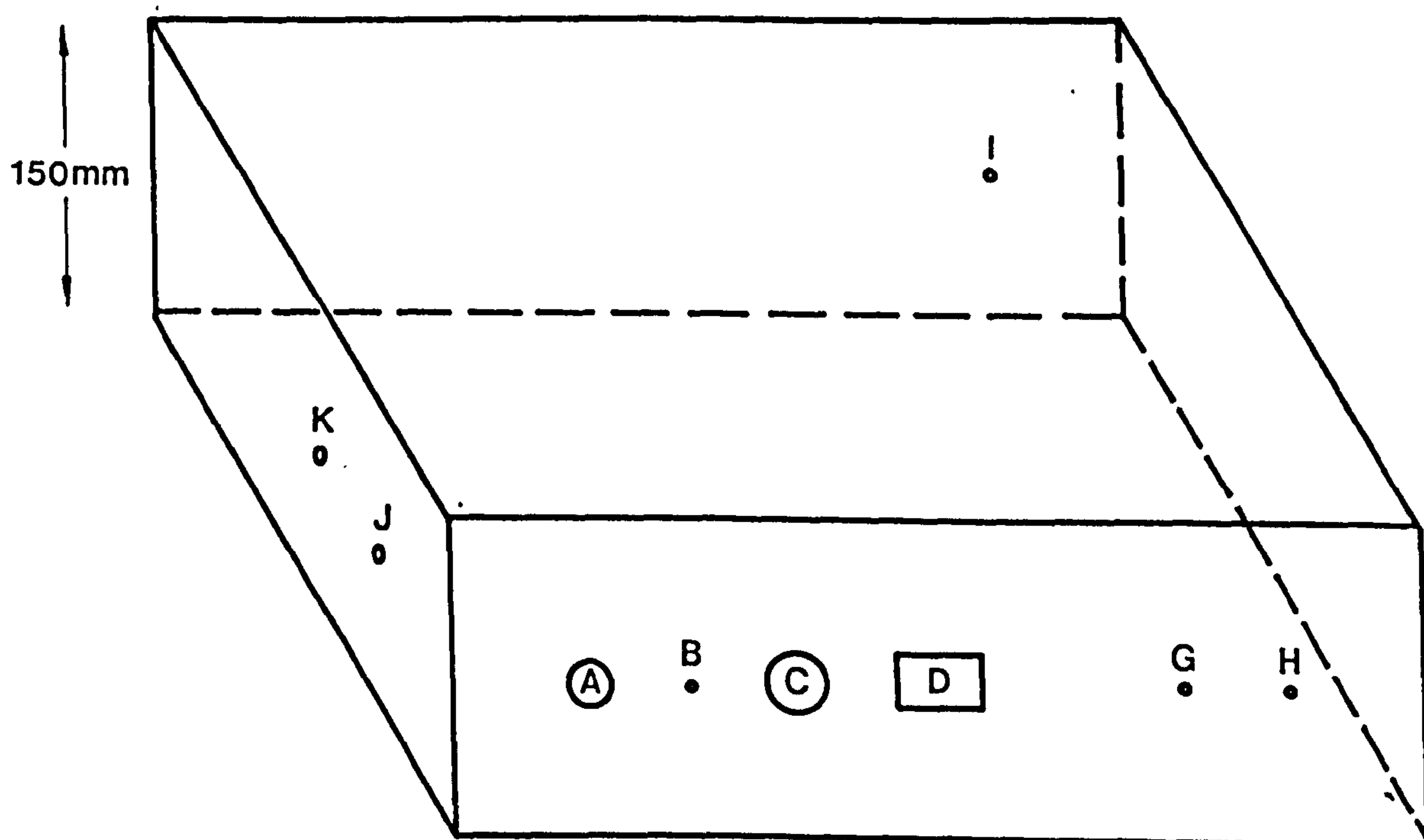
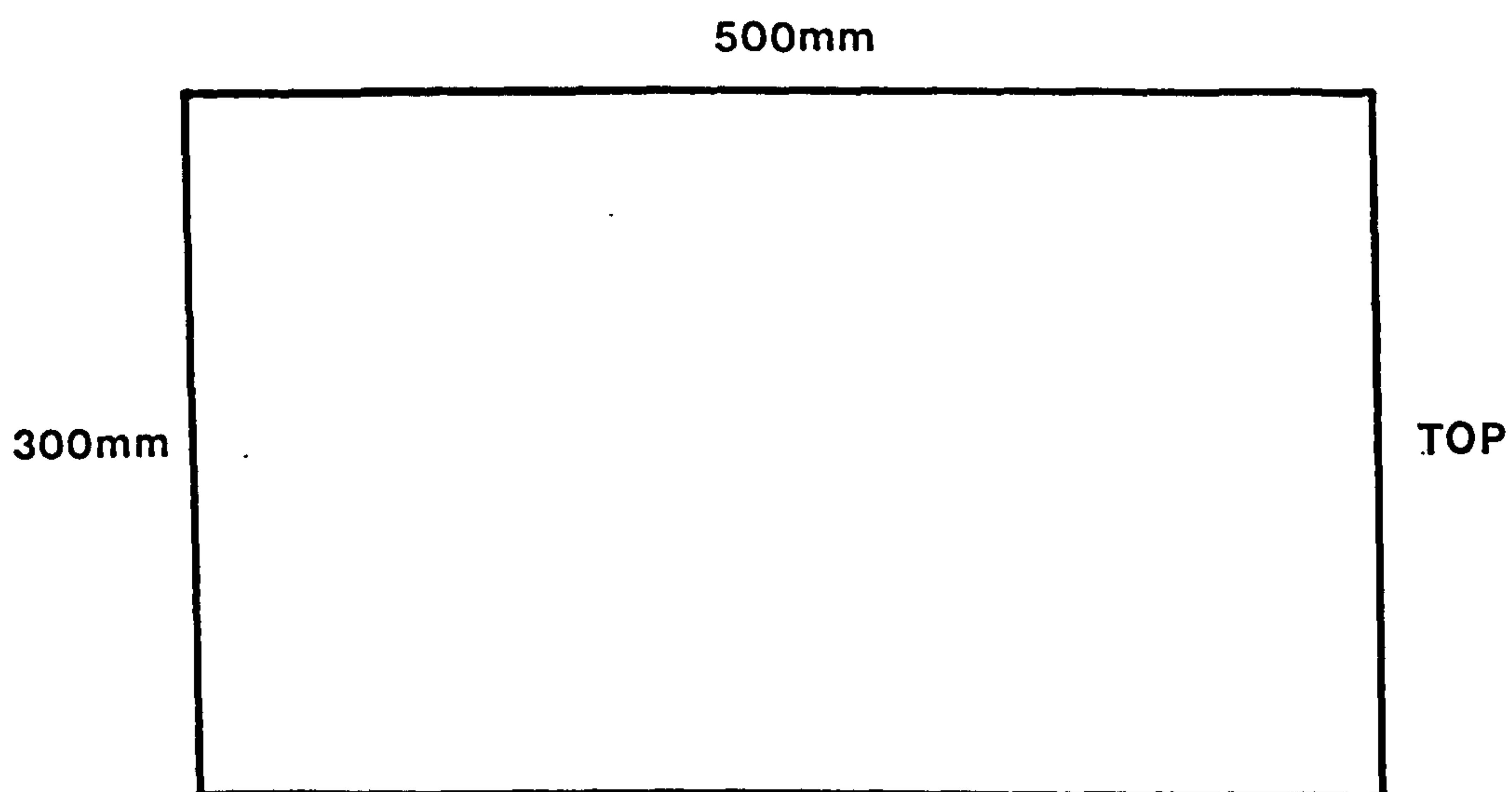


Figure 49 Photograph of Box Used to Mount all Circuitry
Featuring (left to right) Relief Valve, On/Off
Switch, Pressure Gauge, LCD Display and Battery
Supply Switch



- A 25mm DIA
- G, H & B 0.243" DIA
- C 60mm DIA
- D 42 x 22mm DIA
- K, I & J 1/4" DIA

Figure 50 Shows the dimensions and drilling of the box

4.6 Display

This section will cover different displays from LCD to a plotter, that can be used with the pressure sensor.

1. LCD Display

This is a uniquely compact LCD module. The output from the amplifier was directly connected to Pin X of the circuit below:

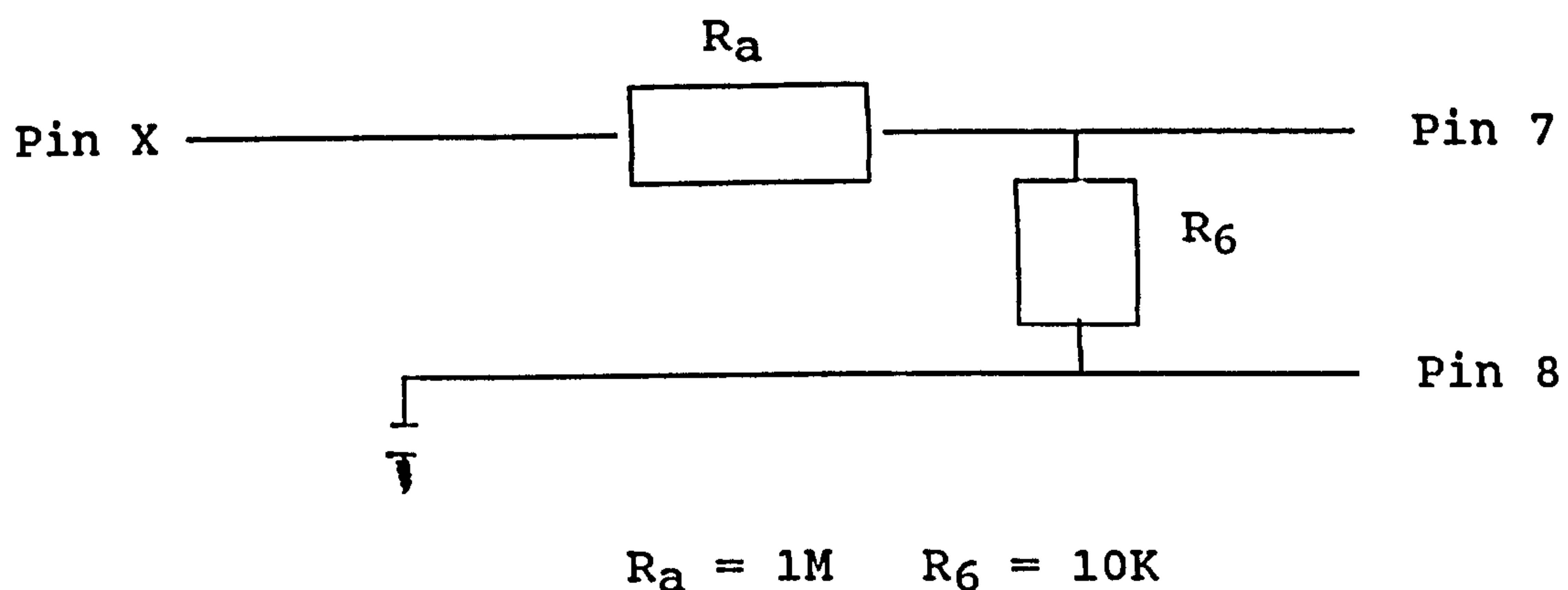


Figure 51 The input connection to the LCD Display Circuit
(Data sheet provided in appendix 3)

One of the features of this LCD module is that it has an auto-zero function, which as it suggests resets the display to zero when the voltage is removed. In this case when the pressure in the pressure sensor is increased and then returned to normal, via the action of the subject pressing on the strain measuring area, the LCD would show the highest reading, and would then reset itself to zero. The positive and negative supplies were connected to a single 9 volt battery.

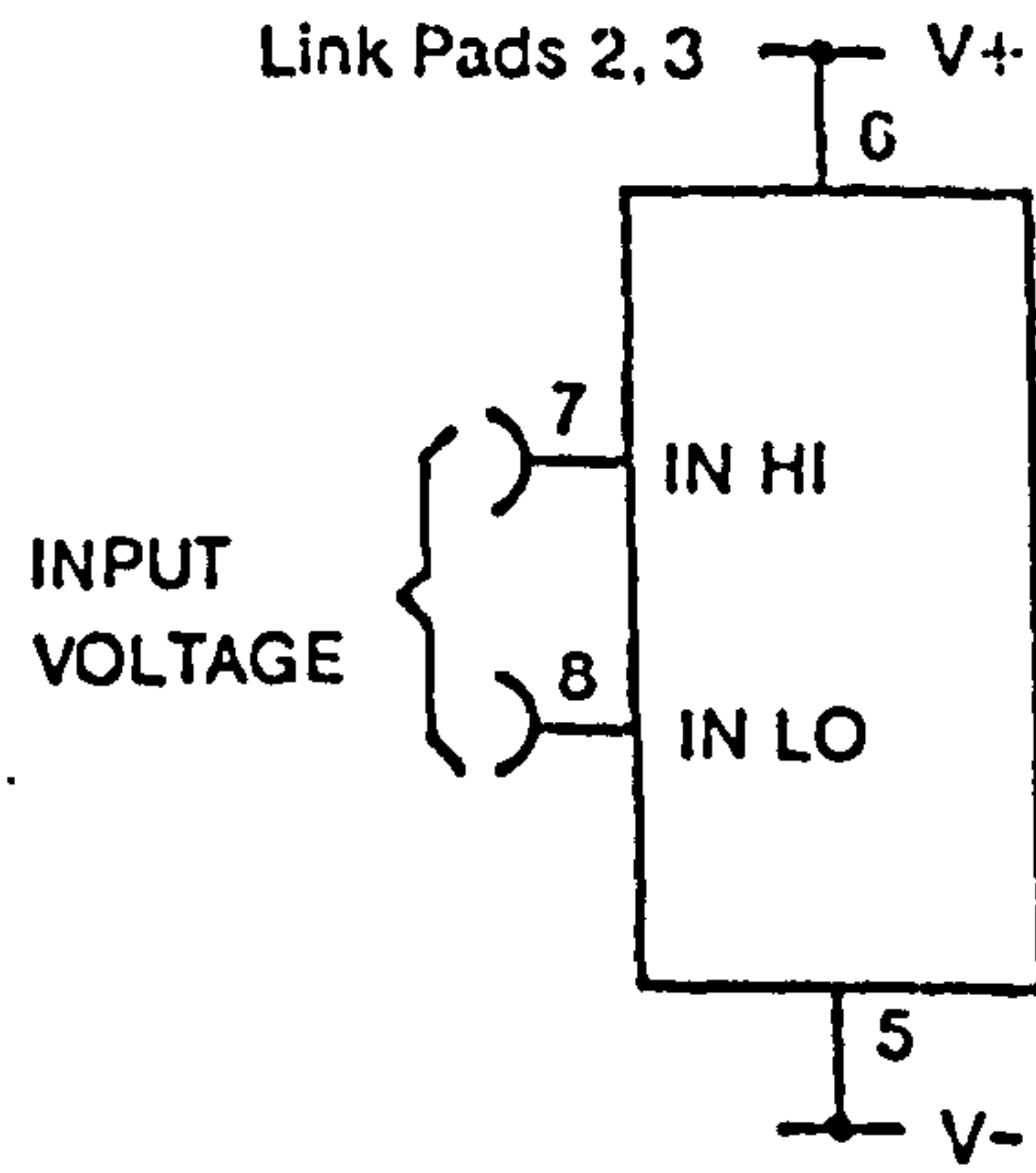
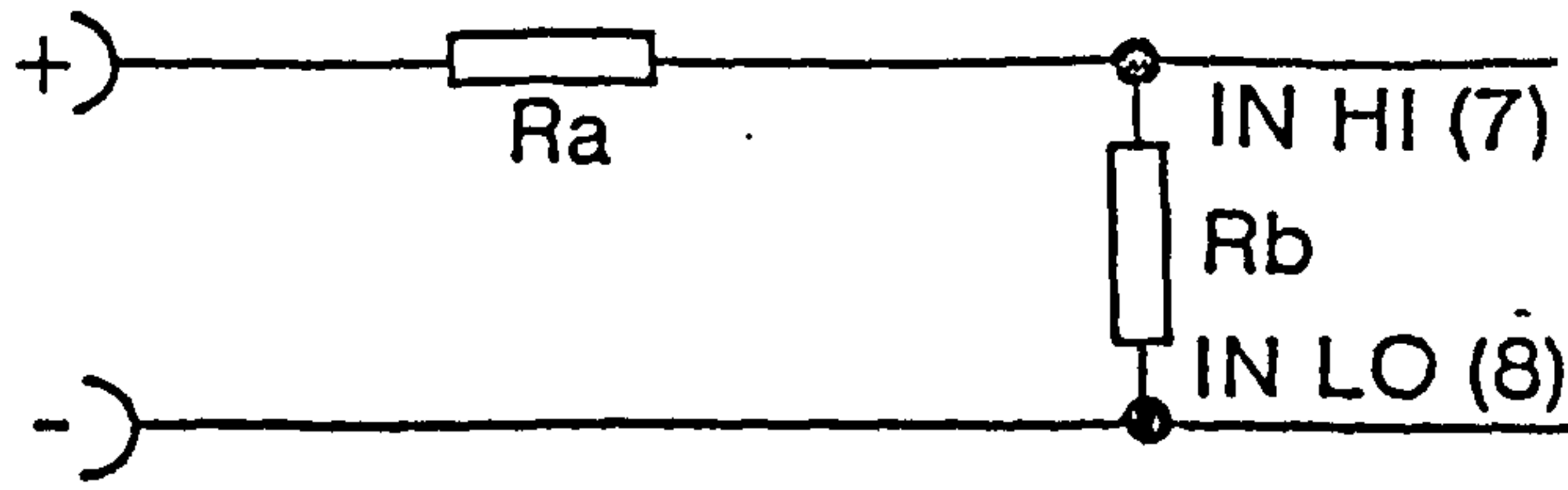


Figure 52 Shows measuring a floating voltage source

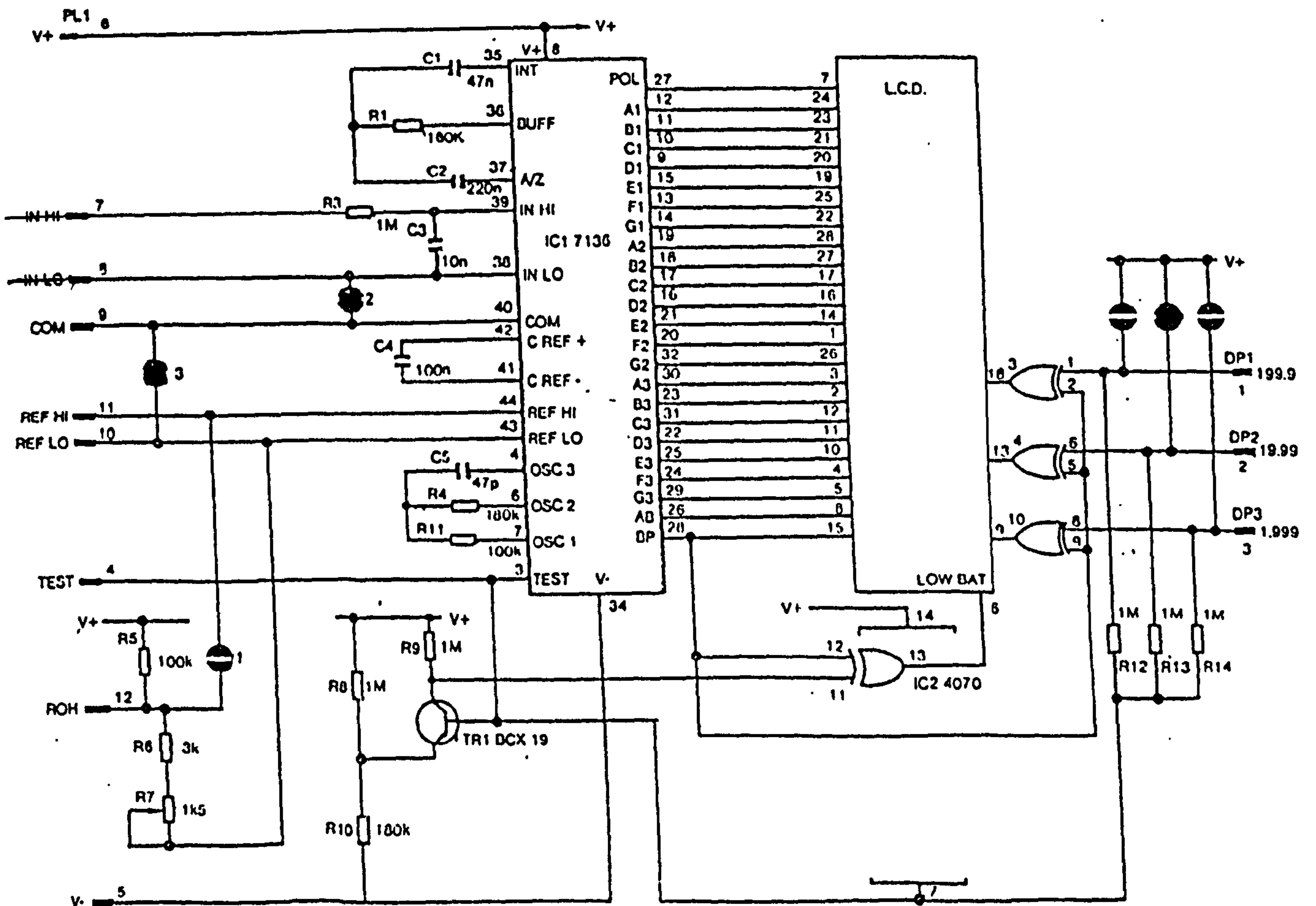


Figure 53 Shows LCD circuit

2. Single Channel Y/T Recorder

One channel Y against time record writing with blue or red disposable markers on a 32 metre roll of 250mm wide chartpaper, and having the facility through quartz controlled speed drive. The input sensitivity from 1mV to 5V with variable controls allowing a 0.4mV full scale to be displayed. The speed can be varied from 10 mm/min to 300 mm/min. This was used in the testing of the muscle strength in this thesis.

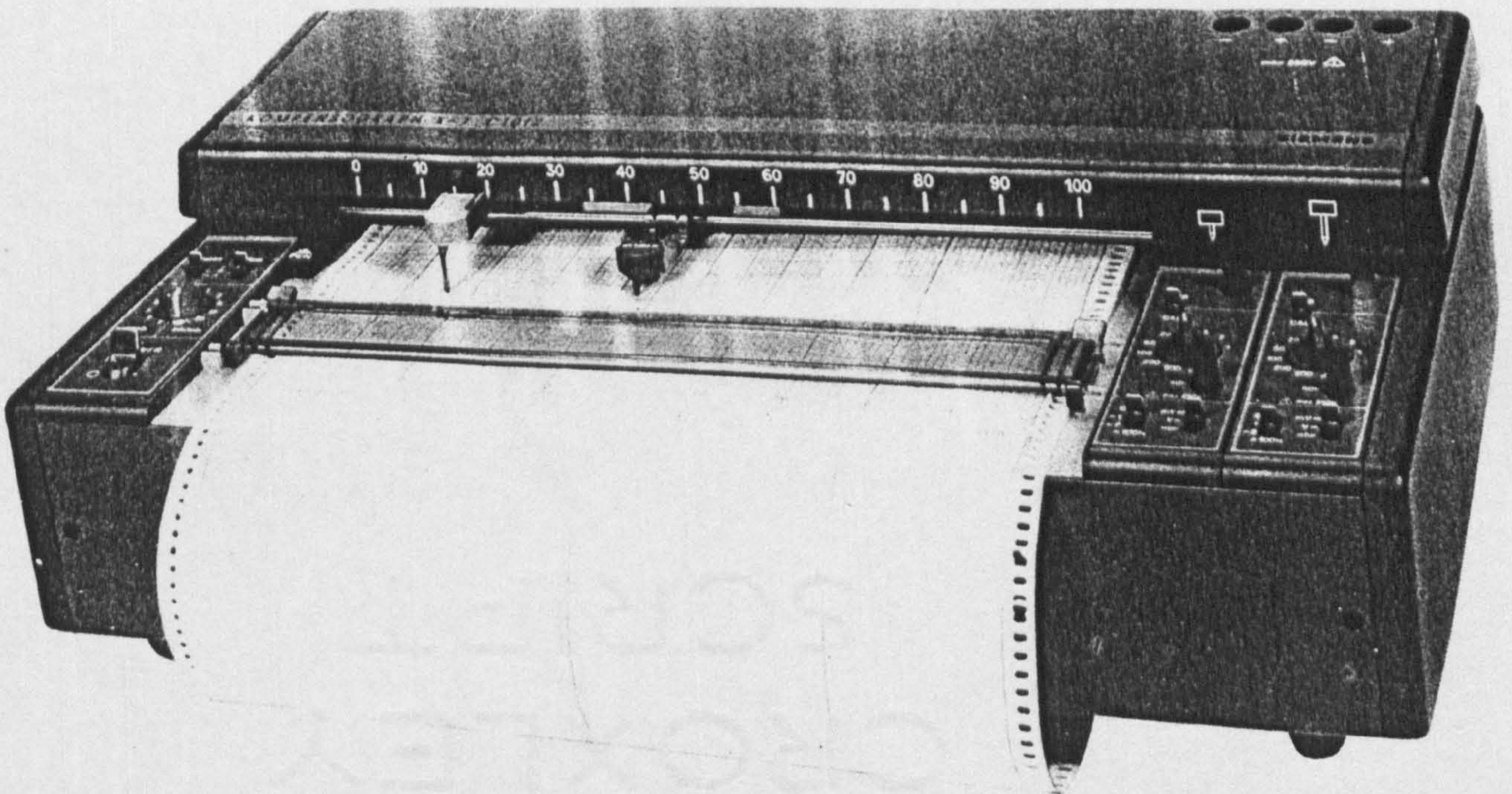


Figure 54 Shows Y/T Chart Recorder used in this thesis

3. Chart Recorder

An inexpensive chart recorder having similar electrical characteristics to a moving coil meter but producing a permanent record on a strip of paper. This is recommended to be used with the muscle strength system, a data sheet is provided in the appendix 4.

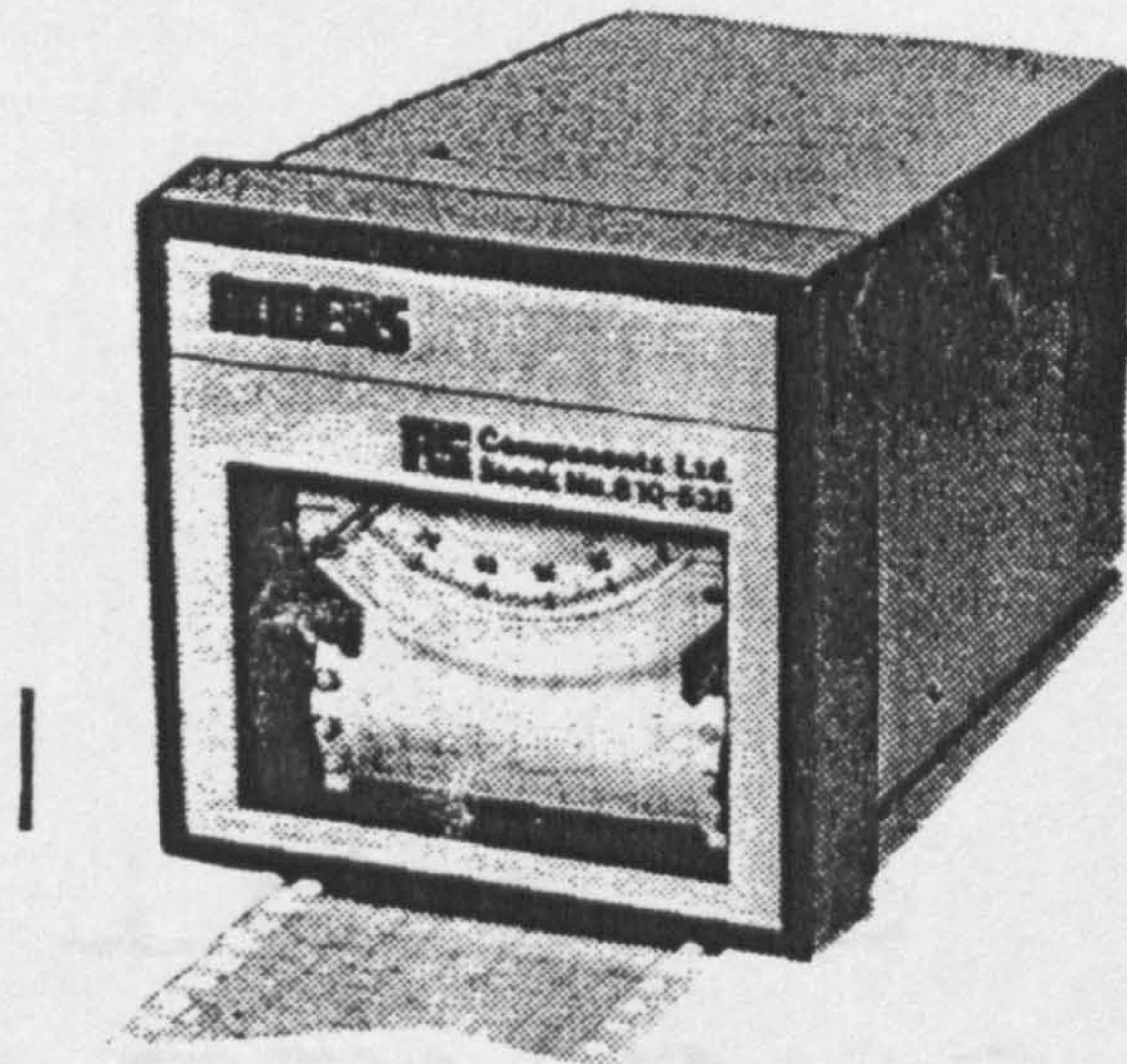


Figure 55 Shows Chart Recorder
Data Sheet provided in appendix 4

4. Plotter

Any graphics plotter can be used with the muscle strength system. The Z80 would have to be programmed for that specific plotter to achieve a good result. This could prove very expensive if such a plotter is not freely available to the user who must also be able to do the necessary programs.

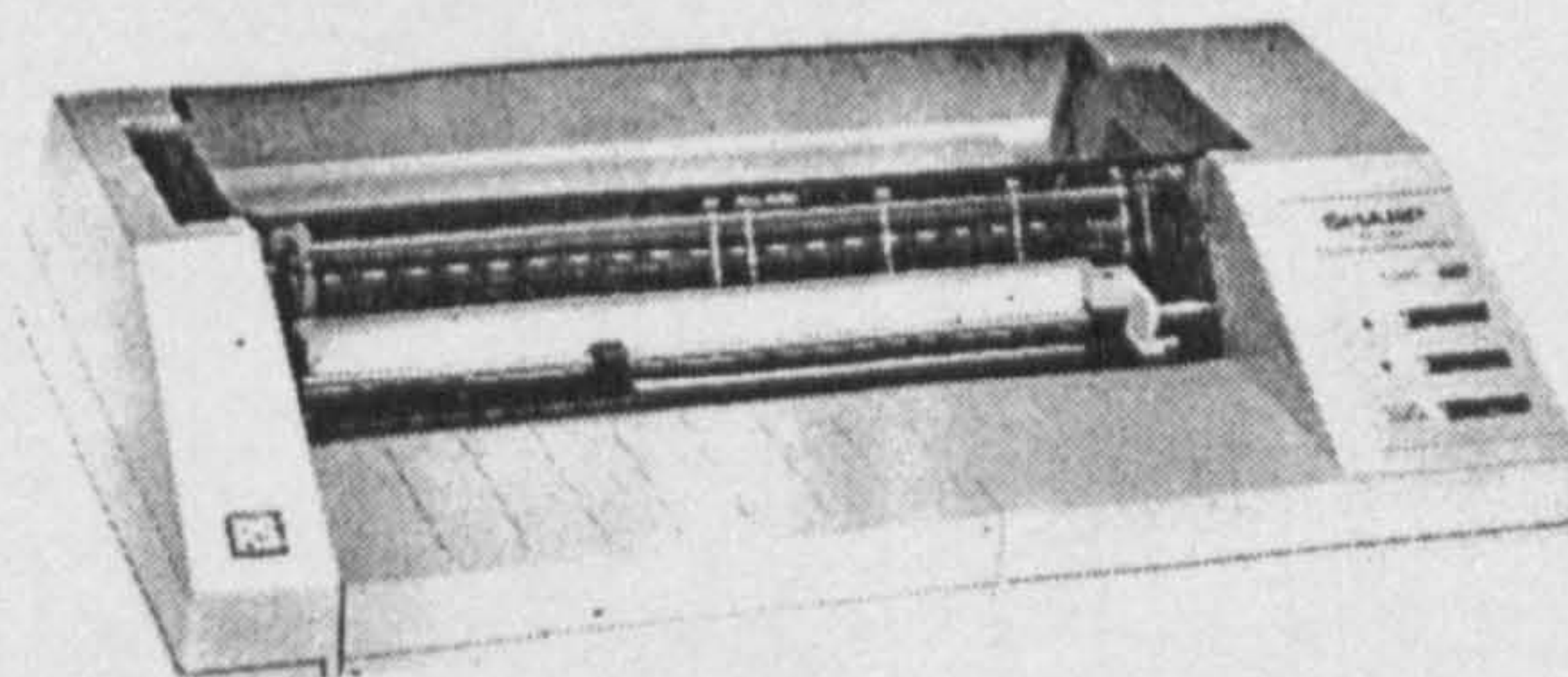


Figure 56 Shows a plotter/printer which can be used

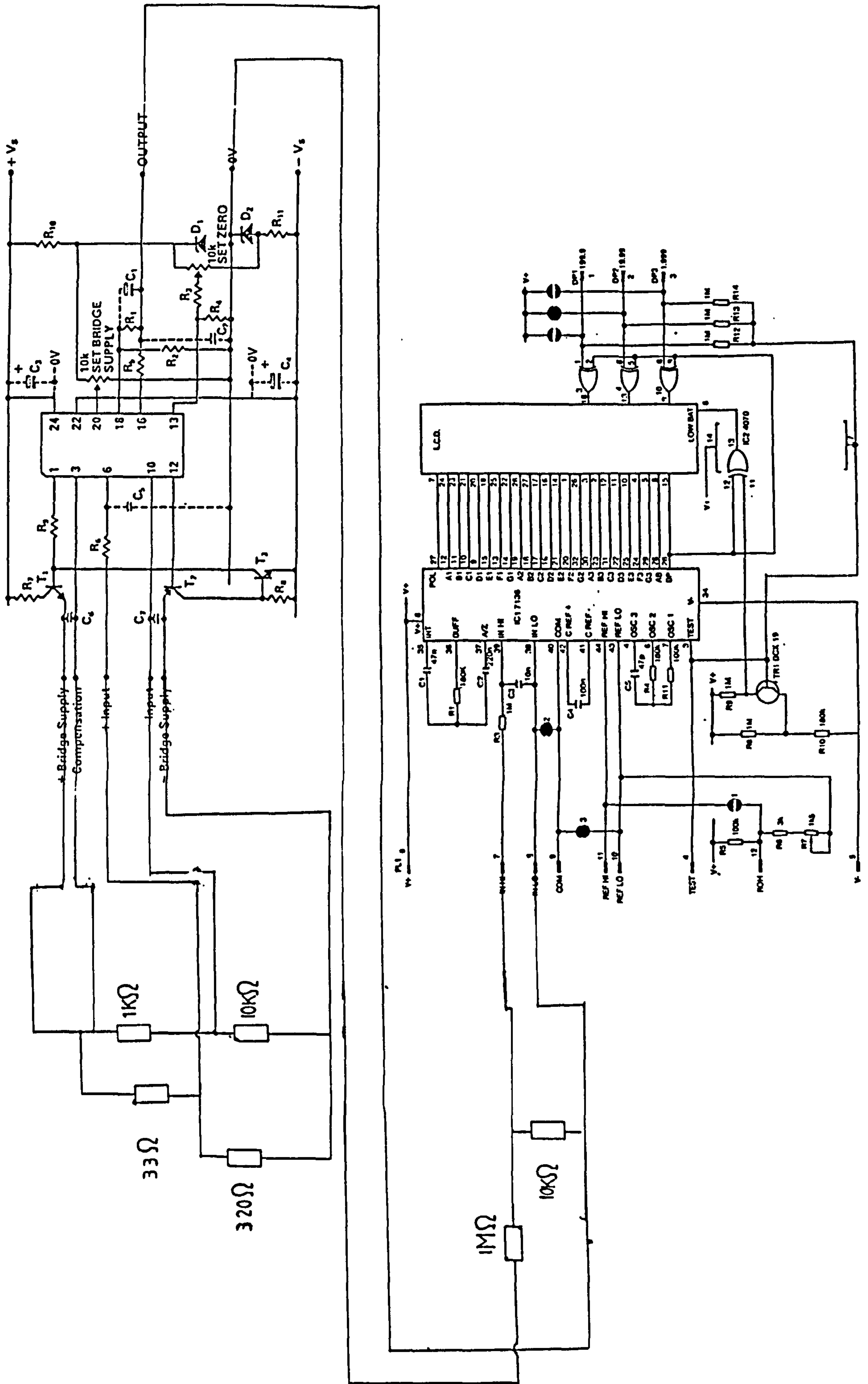


Figure 57 Shows full circuit connection of the electrical section used in the muscle strength system

4.7 Calibration

The screw on potentiometers 1, 2 and 3 can be adjusted until the output is within $\pm 0.1\%$ of zero. Once potentiometer 1 was adjusted it need not be adjusted for future calibration, only potentiometers 2 and 3 can be adjusted for future tests. The gain can be adjusted by changing the ratio of R_1 and R_2 as shown in the formula below

$$\text{Gain } 1 + \frac{R_1}{R_2}$$

C_5 , C_6 and C_7 can be removed for faster output response.

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C_5 , C_6 and C_7 can be removed for faster output response.

CHAPTER 5

5.1

RESULTS

During the development of the muscle strength system each of the pressure sensor prototypes, models 1 - 4, were tested using an amplifier provided by HBM of Oxford, (see appendix 2). The results from the test were digitally displayed. These results were used to give an idea how effective each of the prototypes was and if that prototype needed any modifications.

Once a final system was arrived at, the initial tests were carried out using 15 volunteer patients provided by Dr R Choy. The volunteers were of both sexes, with height ranging from 5' 4" to 6' 2", weight ranging from 8 stone to 14 stone and ages ranging from 22 years to 38 years. The aim was to establish an idea how human muscle reacts to the pressure sensor i.e. if the pressure sensor is too large for some patients' hands or it is too hard to operate or if it is too hard for the patient to understand the principle of operation, which is very important to get an accurate result as will be explained later in this chapter.

During testing it was found as the volunteers progressed through the test they would try to apply more pressure to compensate for the fatigue of the muscle. This would result in the volunteers moving their wrist while they applied pressure, and would result in different readings for the same allergen test as shown in figure 58.

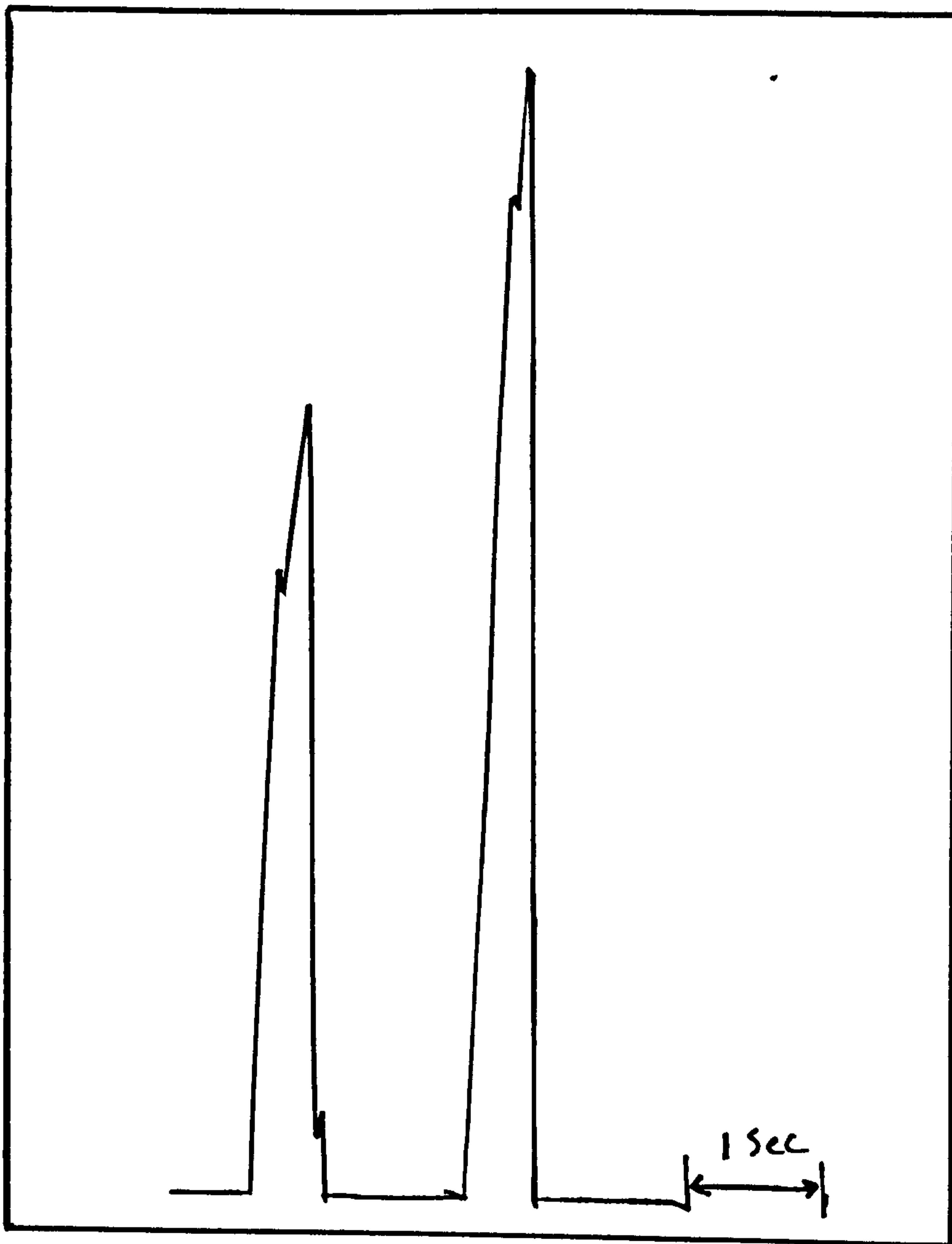


Figure 58 Shows how a wrong result can be obtained as a result of fatigue and the movement of the wrist. Note the sharp top of the graph and also the width each of the graphs, this indicates very sharp release of the pressure switch.

The above conclusion led the author to consider the following points in future tests:

- i. Each test for each of the allergens needed to be repeated twice and an average reading of the two to be taken (this would compensate for any movement of the wrist in either of the two tests).

- ii. A break of 3 - 5 seconds between each depression for each of the allergens. This will allow the muscles to recover from fatigue even if it is only a very small recovery.
- iii. After each patient had been tested for 15 allergens, a break of 3 - 5 minutes was required. This again was to allow the muscles to recover.
- iv. An approx. $\pm 5\%$ margin of error was allowed for when the average of two tests for the same allergen was compared to the natural measurement defined as the measurement carried out without any allergen.

The above 4-points collectively will allow for any wrist movement during any of the tests and also allow for the muscle fatigue, as shown as below in figures 59 and 60. The rest of the results are provided in Appendix 6.

Using the information gathered it was seen that a system with a reliable result had been arrived at. This system could now be used to attempt to prove a relationship between muscle strength and allergic sensitivity. These tests were performed at an established allergy clinic. They were carried out under strict double-blind conditions, that is to say neither the patient nor the author knew what the patient was being tested for, nor did the author know what the patient was/was not allergic to.

In its final version, the test was carried out by loading the piston of Prototype 4 (now referred to as the final system) so that the subject could only achieve 85% compression of the full scale reading (graphic or digital). Once that had been done, a natural reading was taken i.e. without the presence of any allergen. The patient then held the allergen with the free hand and compressed the pressure sensor with the other hand. A reading was then taken for that allergen and repeated after 3 seconds, an average value point was then taken and marked on the graph or chart.

This was repeated for each of the allergens the patient was required to be tested for. A band of $\pm 5\%$ from the natural reading was drawn. If the allergen's average point lay within this band then the patient was considered not to be allergic to that particular allergen, however if it lay above or below it, the patient was considered to be allergic to that respective allergen. Any of the allergens that gave readings that lay above $+5\%$ meant that the muscle had received a boost in strength. This demonstrates that some of the patients have a hyperactivity to the food they are allergic to. If the allergen lay below -5% this demonstrated the weakness of the patient in contact with the food they were allergic to.

After the test had been carried out on each patient, the author marked the $\pm 5\%$ band and then evaluated the results by marking with a circle around each allergen which the patient was sensitive to. Once this had been done, the clinicians compared their results which were arrived at by using traditional tests (see chapter 2) with the graphical results from the pressure sensor and marked each allergen with a tick if they agreed with the results and a cross if they disagree as shown in figure 4.

The specimens were provided on a basis of 1 allergen to 3 placebo. The number of patients to be tested to provide a valid statistical result was determined by Dr. R. Baker. Dr. Baker had worked with many doctors to provide good statistical results for their testing (including the writer's supervisor). She gave a number of between 20 - 30 patients as being necessary to give a valid statistical result for the present tests.

Figure 59 Show how the results from the tests can be read

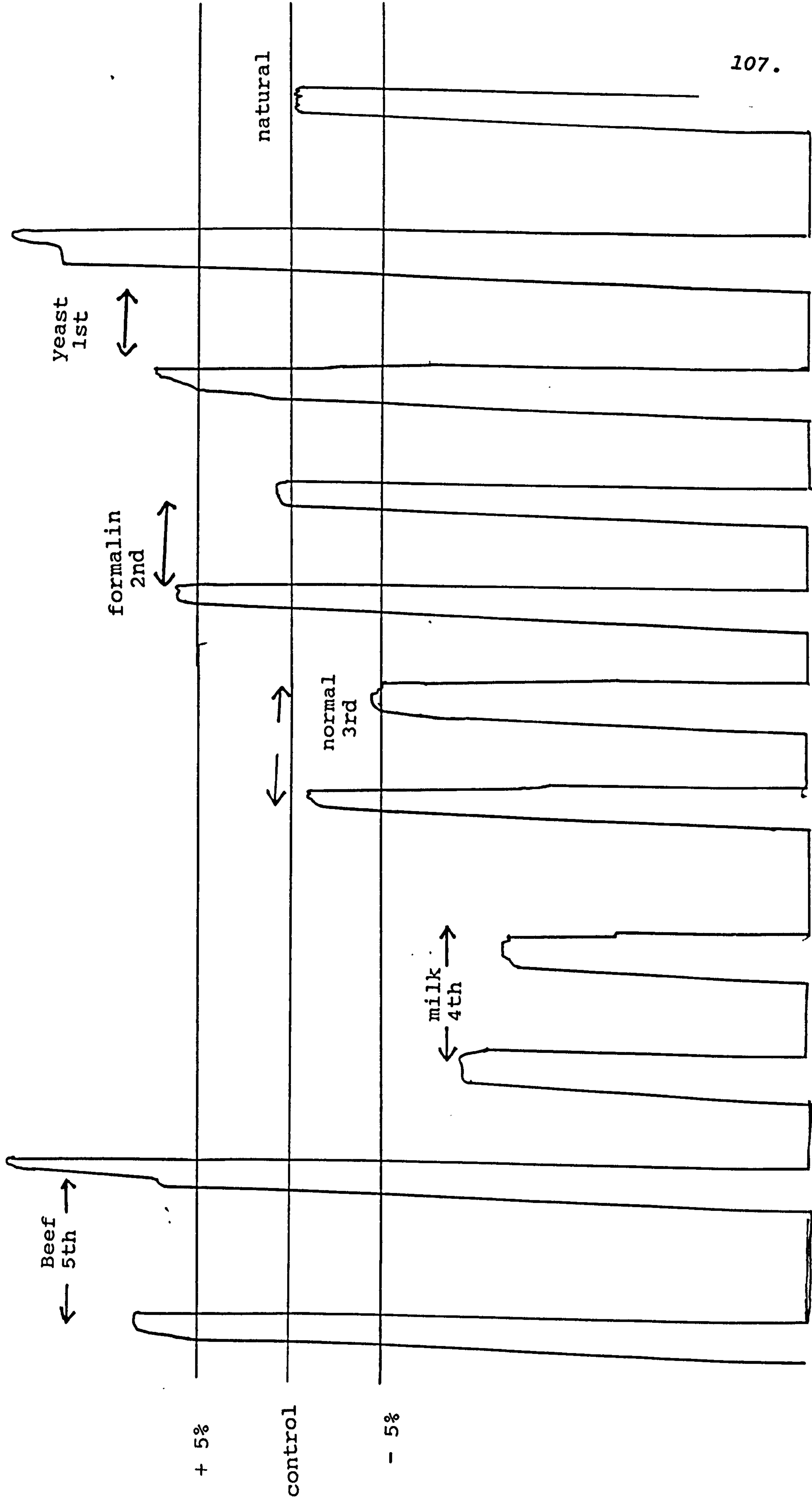


Figure 60 Show how the results can be read

tap water
4th

kiwi fruit
7th

white sugar
5th

orange
3rd

egg
2nd

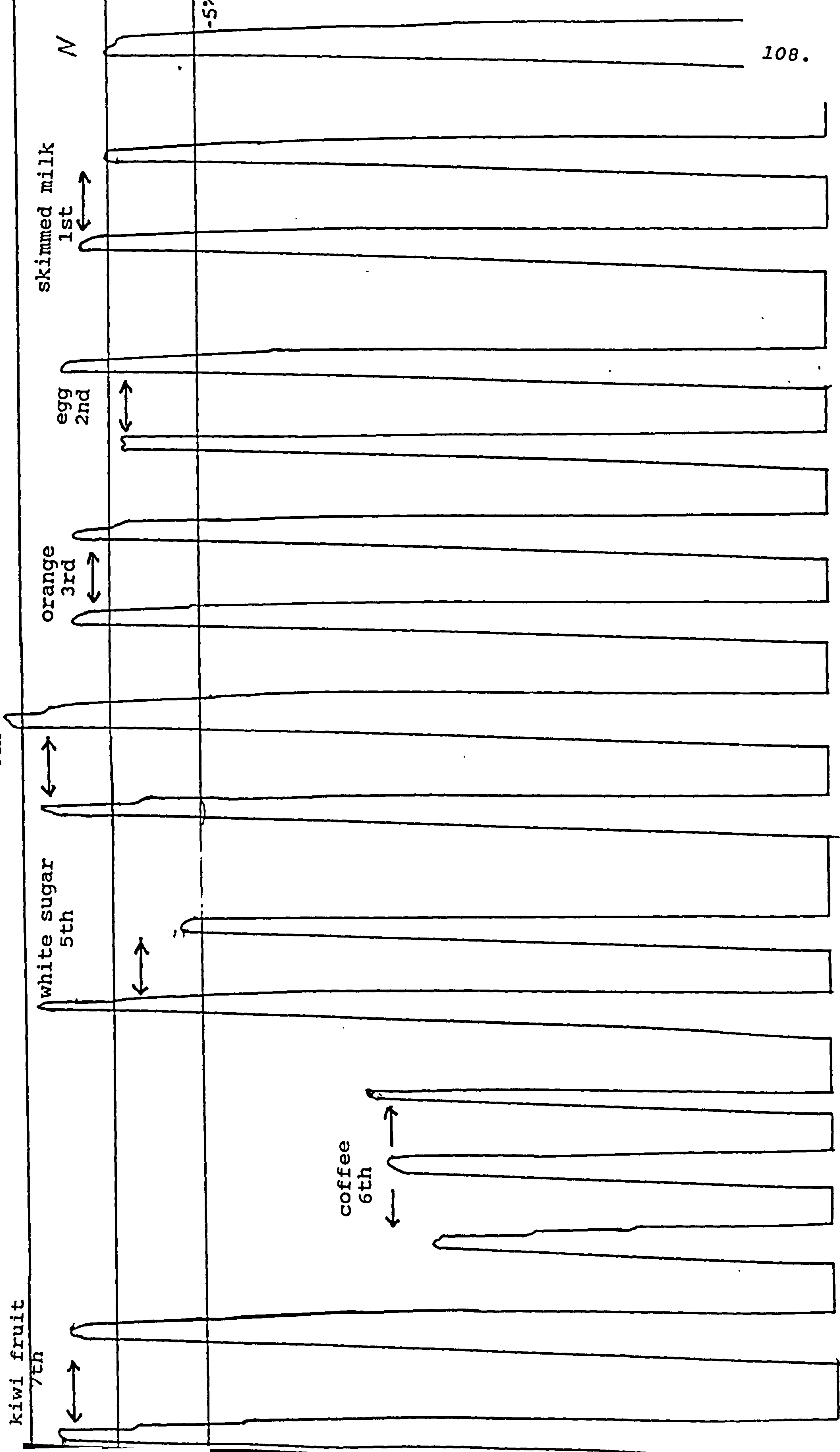
skimmed milk
1st

N

-5%

coffee
6th

+ 5%



5.2 Statistics

Tables which involve only two rows and two columns are usually called 2 x 2 tables. They are very common in statistical practice, where a quick method of analysis is highly desirable. In essence it is comparing two percentages with sufficiently large numbers but the method is in many respects more servicable.

5.2.1 Theory of 2 x 2 tables

Consider a 2 x 2 contingency table whose elements are represented in Table 3.

SECOND CLASSIFICATION	FIRST CLASSIFICATION		TOTAL
	PRESENCE OF A	ABSENCE OF A	
PRESENCE OF B	a	b	a + b
ABSENCE OF B	c	d	c + d
TOTAL	a + c	b + d	n

Table 3 Shows how 2 x 2 Table can be constructed

Brandt Snedecor⁽¹⁾'s formula

$$X^2 = \frac{n (ad - bc)^2}{(a+b)(c+d)(a+c)(b+d)} \dots\dots\dots(1)$$

where X^2 is called the chi-squared value, it is a measure of the extent to which the observed numbers in

¹- Cox D.R., and Hinkley D.V.: Theoretical Studies, London, Chapman & Hall Ltd., 1974

the cells of the contingency table depart from the values we should have if the rows of percentages (each item in each of the rows) were all identical. We then refer to the table of χ^2 distribution to see whether the observed value is larger than would be expected by chance or a Null Hypothesis that postulated no association whatever between two classifications.

5.2.2 Construction of 2 x 2 tables

The results were required to be displayed statistically. 2 x 2 tables are common in this field and this was the method chosen. 2 x 2 tables were constructed for each allergen tested, see Clinical Trials Table 1. The example given below shows the rows representing the Muscle Testing System Results and the columns representing the Clinical Testing System

		Muscle Strength	
		NO	YES
Clinical Test	NO	a	b
	YES	c	d

Therefore if the patient tested proved to be positive, i.e. allergic, by the muscle-testing system a mark was made in the 'yes' column, if they were also proved positive by clinical methods, then a mark was made in the 'yes' row.

The table below shows this result statistically.

		MUSCLE STRENGTH TEST	
		NO	YES
CLINICAL TEST	NO		
	YES		/

If the patient was found to be positive by the muscle-testing system and negative by the clinical test a mark would be made in the box b as shown below, etc., etc.

		MUSCLE STRENGTH TEST	
		NO	YES
CLINICAL TEST	NO		/
	YES		

The 2 x 2 tables were constructed for each allergen with one for male and one for female subjects. These are shown on the following pages.

	<u>MALE</u>	<u>FEMALE</u>	<u>MALE</u>	<u>FEMALE</u>
	orange		onion	
	NO YES			
NO	I	III III		IIII
YES		I		
	egg		kiwi fruit	
	II	II	III III	III III
			I	III
	skimmed milk		brown sugar	
	II	III		I
	white sugar		cheese	
	II	III I	II	IIII
				I
	tap water		coffee	
	III	III I	I	IIII
			II	IIII
	lamb		pineapple	
	III III	III	III I	II I
			II	I

	<u>MALE</u>		<u>FEMALE</u>		<u>MALE</u>		<u>FEMALE</u>	
	onion soup		sharon fruit		butter cream		haricot bean	
	NO	YES	NO	YES	NO	YES	NO	YES
NO	III III		II		III III		III	
YES		II		I		I		I
	capsicum		peach		strawberry		chicken	
NO	III III		III I		III I		I	
YES		I		III		III		
NO	III III		III III		III		I	
YES				I				
NO	III I		III		III		I	
YES		III		I				

Table 4 Using Table 3 a table of 2 x 2 was constructed for each of the allergens, one for male and one for female

Using the previous tables a Master Table was constructed for both Male and Female results as shown below:

MUSCLE TEST

		<u>MALE</u>				<u>FEMALE</u>			
		NO	YES			NO	YES		
<u>Clinical</u>	NO	a'	b'		NO	a'	b'		<u>Clinical</u>
<u>Test</u>	YES	c'	d'		YES	c'	d'		<u>Test</u>

Each table was constructed by adding all the numbers in each relevant box, e.g. the number of marks made in box a' during the clinical tests were all added up. The same was then done for b', c' and d', both for males and females.

5.2.3 Test results

Using Table 4 two 2 x 2 tables were constructed, one for male and one female, each table was constructed by adding all the observations which resulted from testing patients for allergies, by adding all the boxes of the 2 x 2 tables to form one 2 x 2 table as shown below:

		<u>MALE</u>				<u>FEMALE</u>			
		NO	YES			NO	YES		
NO		90	1	91	row total	NO	86	3	89
YES		0	24	24	row total	YES	0	26	26
		90	25	115			86	29	115
		column total	column total	column + row total					

Using the above two tables, an association between the clinical testing and muscle testing systems was calculated. This was done by entering the data into the Prime computer at Salford University.

The program and data used for this are given below.

Program for Prime Computer Containing Data From Tests

Title 'Tables with weighting'

DATA LIST FREE/SALFORD,CLINIC,COUNT

WEIGHT BY COUNT

CROSSTABS TABLES=SALFORD BY CLINIC

STATISTICS 1

BEGIN DATA

ROW	COL	MALE	FEMALE
1	1	90	(86)
2	2	0	(0)
1	2	1	(3)
2	2	24	(26)

END DATA

finish

The computer operates to four decimals. The significance from the computer calculation shows 0.0000 for male and female. Therefore it is safe to say that there is a very high association between the muscle testing system and clinical results, only differing from 100% by 1 in 10^{-4} , which is negligible.

5.2.4 The manual calculation

To find the significance between muscle strength and clinical test, the χ^2 values for male and female were looked up in Fisher's Table (see appendix 5). Fisher's Table calculates the significance for different degrees of freedom. To calculate the degree of freedom for a 2 x 2 table the formula below was used.

$$\text{Degree of freedom} = (\text{row} - 1) (\text{column} - 1)$$

$$\text{therefore the degree of freedom} = 1$$

Because of the good experiment results obtained, the only way to demonstrate statistically is by manual calculation

Therefore to calculate χ^2 for male:

$$\chi^2 = \frac{(90 \times 24)^2 \times 115}{90 \times 91 \times 24 \times 25}$$

$$\text{therefore } \chi^2 = 109.1868$$

to calculate χ^2 for female:

$$\chi^2 = \frac{(86 \times 26)^2 \times 115}{89 \times 26 \times 86 \times 29}$$

$$\text{therefore } \chi^2 = 99.62$$

Then looking up the value of χ^2 for male and female for a degree of freedom of 1 in Fisher's table, as the Table available can only go to three decimal places (i.e. less than 0.001) it is possible to say that the association is again very high. It is also concluded that the apparatus did not show any bias to the physically stronger or weaker sex.

CHAPTER 6

6.1

CONCLUSIONS

During the past few decades a few methods have become available to doctors and other clinical practitioners to test for allergies. These methods include the Skin-Prick Test, Scratch Test, RAST Test etc, see Chapter 2. However during the past decade other methods have been developed because some of these doctors and practitioners, particularly in the United States, were not happy with existing methods.

Among these new methods are Elimination Diets and Applied Kinesiology. However some patients and their Insurance Companies were not happy with these testing methods due to the fact that there was no physical evidence to prove the results. The hard work and effort of the patients who had been subjected to trials of these new tests only provided subjective data.

The system developed in this thesis proved to be easy enough for patients to operate themselves and showed digitally and graphically any change that occurred in response to a respective allergen.

To test the muscle strength, the system uses a group of muscles between the thumb and first two fingers.

The initial brief for this thesis was to show a relationship between muscle strength and allergic

reaction. From it many points arose but the portability and accuracy of the final system were thought to be the most beneficial. It also gave results that were easily compared with present day methods and was without any side effects on the patient.

Another "plus point" for the system was its 'painless' testing. No need for eliminating certain foods over a period of time. No need for irritating allergens to be taped on to the patient's back, nor was there any need for the skin to be broken or pricked causing more discomfort.

The drawbacks were only slight. Females had a problem with depressing the strain measuring area whilst the piston was under load. This is shown in figure 58, chapter 5.

The problem arose from releasing the thumb from the strain measuring area too quickly, therefore familiarisation between subject and system was required. To eliminate any false readings two readings were taken and the average point used for statistical analyses.

In some of the results it was found that the females showed a response in testing that they were allergic to fruit and vegetables they were eating as part of their diet, (an eliminating diet had been used by the allergy clinic to detect their allergy). This may be attributed to food intolerance.

It was then felt with proper resources and patients to prove that the system could be of use in detecting food intolerance, without the need for the patient to go on a special elimination diet.

The system can be used on subjects of all ages without the current irritations of present day testing.

Muscle fatigue was an important factor to take into consideration in the tests. Therefore after testing 15 allergens on a patient a rest period was required to allow the muscle to relax and recover. This rest period was approx 3 - 5 minutes, that could vary from patient to patient.

Taking into account the rest periods and the length of time it took to test a patient over a range of allergens, the system still proved to be faster by far than any of the current testing methods available.

In summing up the system, it is portable, reliable and accurate in producing graphical and digital results on a regular basis, but perhaps more importantly it shows clear evidence of a relationship between muscle strength and allergic reaction, whilst being non-painful and providing results quickly. This work will open the way for clinicians to have objective assessment of this relation and for researchers to find the reasons why there is this relationship between muscle strength and allergic sensitivity.

6.2 Total costing of the system

This table shows the cost of every component used in this system so budgeting can be made in future work if it is needed.

	Number Required	Price
Resistors	1 pack	£2.00 per pack
3/8 in square potentiometer	3	£1.02 each
Multi-turn potentiometer	1	£8.64 each
Transistor	3	£1.69 each
Diodes	2	£2.50 each
Strain gauge amplifier	1	£25.50 each
Compactors	1 pack	£0.76 per pack
4-way connectors	1 pack	£1.99 per pack
3-way connectors	1 pack	£1.39 per pack
Strain gauge amplifier P.C.B.	1	£2.57 each
Strain gauge	1	£4.99 each
Strain gauge cleaning & adhesive	1	£50.00 each
Electrical air compressor	1	£15.99 each
Reducing union	1	£6.75 each
Relief valve	1	£21.10 each
Port connectors	2	£2.00 each
One way valve	1	£10.25 each
Tee connector	1	£4.90 each
Connector to Air compressor	1	£1.90 each
Connector to gauge	1	£1.00 each
L.C.D.	1	£24.00 each
Switches	3	£1.38 each
Pressure gauge	1	£7.00 each
Chart recorder	1	£175.00 each

A/D converter	1	£5.02 each
Z80 (Maplin)	1	£13.95 each
28 kit (Maplin)	1	£29.95 each
Power supply converter	1	£10.69 each
Mechanical work for the pressure sensor (including material)		£80.00
		<hr/>
	TOTAL	£526.61

GLOSSARY

ADHERE	<i>Stick fast (to substance)</i>
ADHESIVE	<i>Sticky (substance)</i>
ALLERGEN	<i>An extract of substance such as food</i>
ALLERGY	<i>Condition of reaction adversely to certain foods, pollens, etc.</i>
ALLOY	<i>Mixture of metals</i>
AMPLIFIER	<i>Enhance, increase strength (electrical signal)</i>
ANAPHYLIC	<i>General shock reaction</i>
ANTI BODY	<i>Protein in the human body produced by counteracting antigens</i>
ANTIGEN	<i>Substance that stimulates production of antibodies</i>
ANTI HISTAMINE	<i>Substance counteracts effect of the presence of a substance throughout the body causing some allergic reaction.</i>
ASTHMA	<i>A disease of respiration, characterized by difficult breathing.</i>
BAND WIDTH	<i>Region of frequency systems operate within.</i>
CLINICIAN	<i>Medically qualified person who works at a clinic</i>
CLINIC	<i>Place where medical treatment is given.</i>
COLIC	<i>Gripping pain in belly.</i>
CONVALESCENCE	<i>Recovering from illness.</i>
DERMATOLOGIST	<i>Clinical specialising in the study of skin and its diseases.</i>
DERMATITIS	<i>Inflammation of the skin.</i>
ECOLOGY	<i>Branch of biology dealing with relations of organisms to one another and their surroundings.</i>
ECZEMA	<i>Inflammation of skin with itching and discharge of vesicles.</i>
ELECTRO MYOGRAPHIC	<i>The recording of changes in electric potential of the muscle.</i>
EPIDERMAL	<i>Outer layer of animal's skin.</i>

EXPECTORATE	<i>Cough or spit out (phlegm etc.).</i>
FIBRE	<i>Thread like cell or filament in animal.</i>
HAMSTRING	<i>One of five tendons at the back of the knee.</i>
IDIOSYNCRASY	<i>Mental constitution, view, feeling, particular to a person.</i>
IgE	<i>Anti body molecules, their function to defend the body.</i>
IMMUNOLOGY	<i>Study of resistance to infection.</i>
KINESIOLOGY	<i>Study of human movements, referring particularly to their use in treatment.</i>
MASKED REACTION	<i>Disguised reaction.</i>
MIGRAINE	<i>Recurrent headache with characteristic features.</i>
MOLECULES	<i>Smallest particle group of atoms.</i>
MUCOUS	<i>Slimy substance secreted by mucous membrane.</i>
MUSCLE	<i>Any of the contractile fibrous band.</i>
NECROSIS	<i>Death of tissue.</i>
ORTHODOX	<i>Conventional.</i>
PAEDIATRICIAN	<i>Clinician dealing with children.</i>
PAROXYSM	<i>Fit of disease.</i>
PERSPEX	<i>Plastic.</i>
PHYSICIAN	<i>One who practises the healing arts. Usually refers to a medically qualified clinician as distinct from a surgeon.</i>
PHYSIOLOGY	<i>Science of functions and phenomena of living organisms and their past.</i>
PHTHISICAL	<i>Progressive wasting disease.</i>
PROTOPLASM	<i>The colloidal complex of protein.</i>
STIMULUS	<i>Increases bodily or mental activity.</i>
SYNTHESIS	<i>Artificial production of substance.</i>

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practice*
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Components required for the system, their
manufacturers, the address of the manufacturers,
part stock numbers and a description of the parts

Addresses of manufacturers

Manchester Valve and Fitting Co. Ltd.,
3 Kelvin Close,
Science Park North,
Birchwood,
Warrington,
WA3 7PB

Tel: 0925 822662

R. S. Components Ltd.,
Kennedy Way,
Green Lane Industrial Estate,
Stockport,
Cheshire,
SK4 27T

Tel: 061 477 8400

Maplin
8 Oxford Road,
Manchester

Tel: 061 236 0281

Schenck Limited,
Dept. HBM,
Station Approach,
Bicester,
Oxon.,
OX6 7BZ

Tel: 0869 321321

Components List Parts for R. S. amplifier

Component	Value	Stock No.	Quantity Required
R1 & R3	100k Ω	148-972	1 pk
R2 & R6	100 Ω	148-269	1 pk
R4	68 Ω	148-219	1 pk
R5 & R8	10 Ω	148-017	1 pk
R7	47 Ω	148-174	1 pk
R9	1K Ω	148-506	1 pk
R10 & R11	680 Ω	148-461	1 pk
VR1 & VR2	10K	186-520	2
D1 & D2	IN827	283-104	2
C1, C6 & C7	100nF	114-840	1 pk
C2 & C5	10nF	114-812	1 pk
C3 & C4	10 μ F	103-957	1 pk
T1	BD135	294-738	1 pk
T2	BC108	293-533	1 pk
4-Way Connector	-	423-762	1 pk
3-Way Connector	-	424-686	1 pk
IC Socket 24-pin	-	402-327	1 pk
Strain Gauge Amp	-	308-815	1

Parts for the Air Pressure connection

All parts are from Manchester Valve Company (see address above)

Stock Number	Description
1) B-400-6-3	Reducing union
2) B-42V54	Relief valve
3) B-401-PC	Port connector
4) B-4C-1	One way valve
5) B-400-3	Tee junction
6) B-80-6-4	Connector to pump
7) B-401-PC	Connection to the pressure gauge

Parts for convertor

(From R. S. address, above)

633-694	A/D Convertor ZN439
---------	------------------------

Z80 Microcomputer

(Maplin address above)

6B86T	Z80 PCB
LK67X	Z80 kit

Part for Wheatstone Bridge

(R. S. address, above)

186-520	Potentiometer
---------	---------------

APPENDICES

APPENDIX 1

Show draft drawings of:

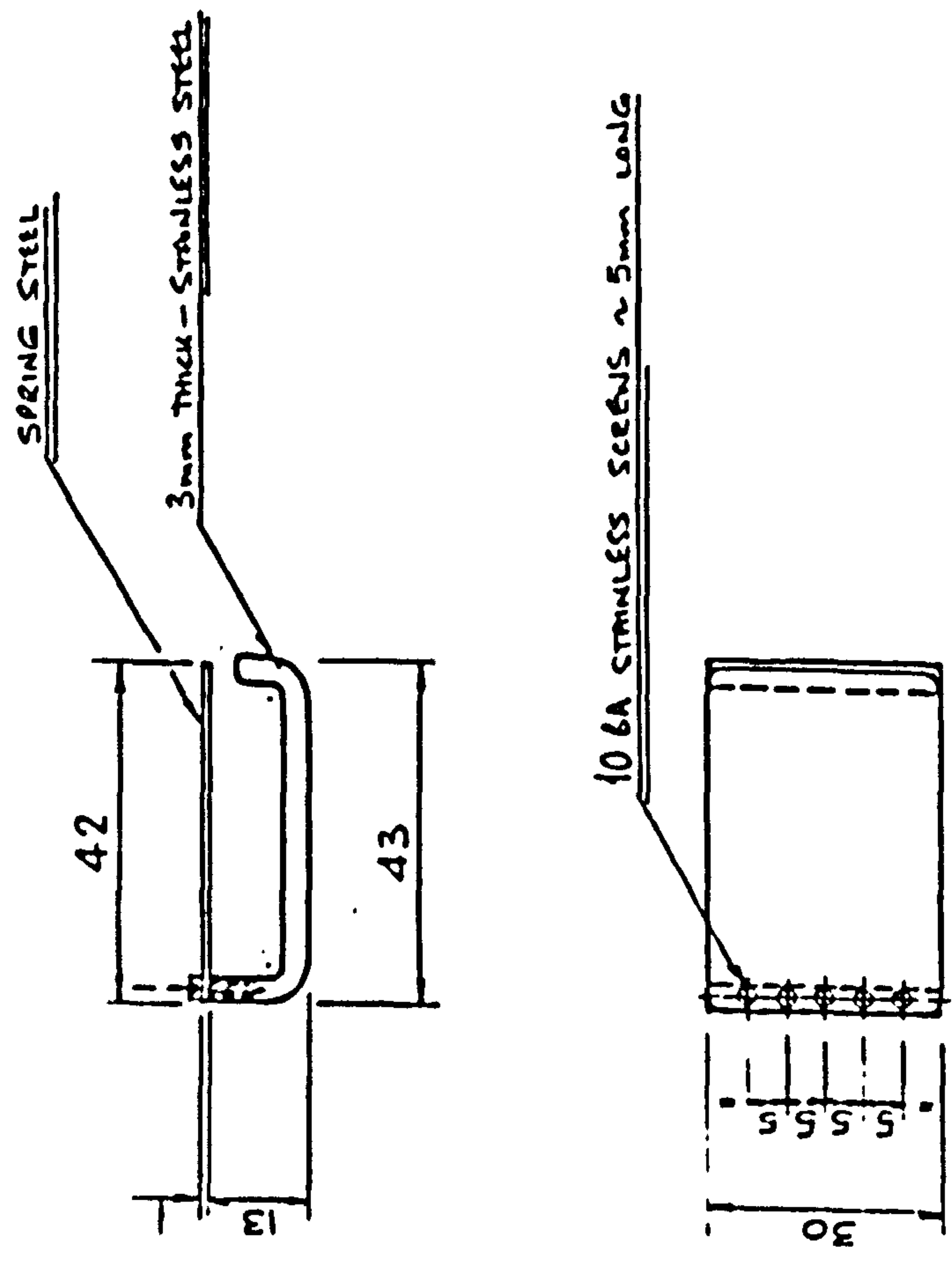
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Prototype 2

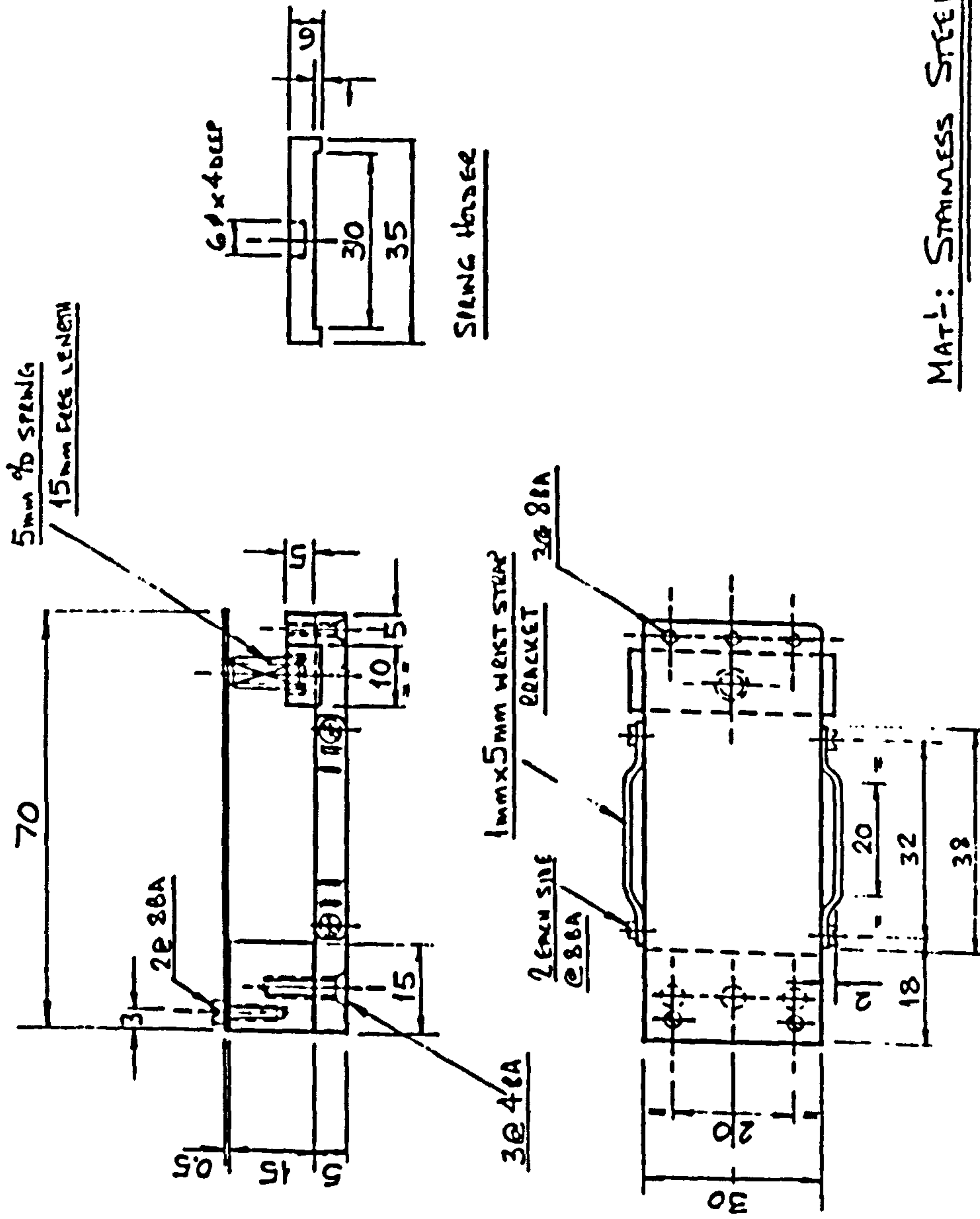
Prototype 3

Prototype 4 - the final version

prototype 1

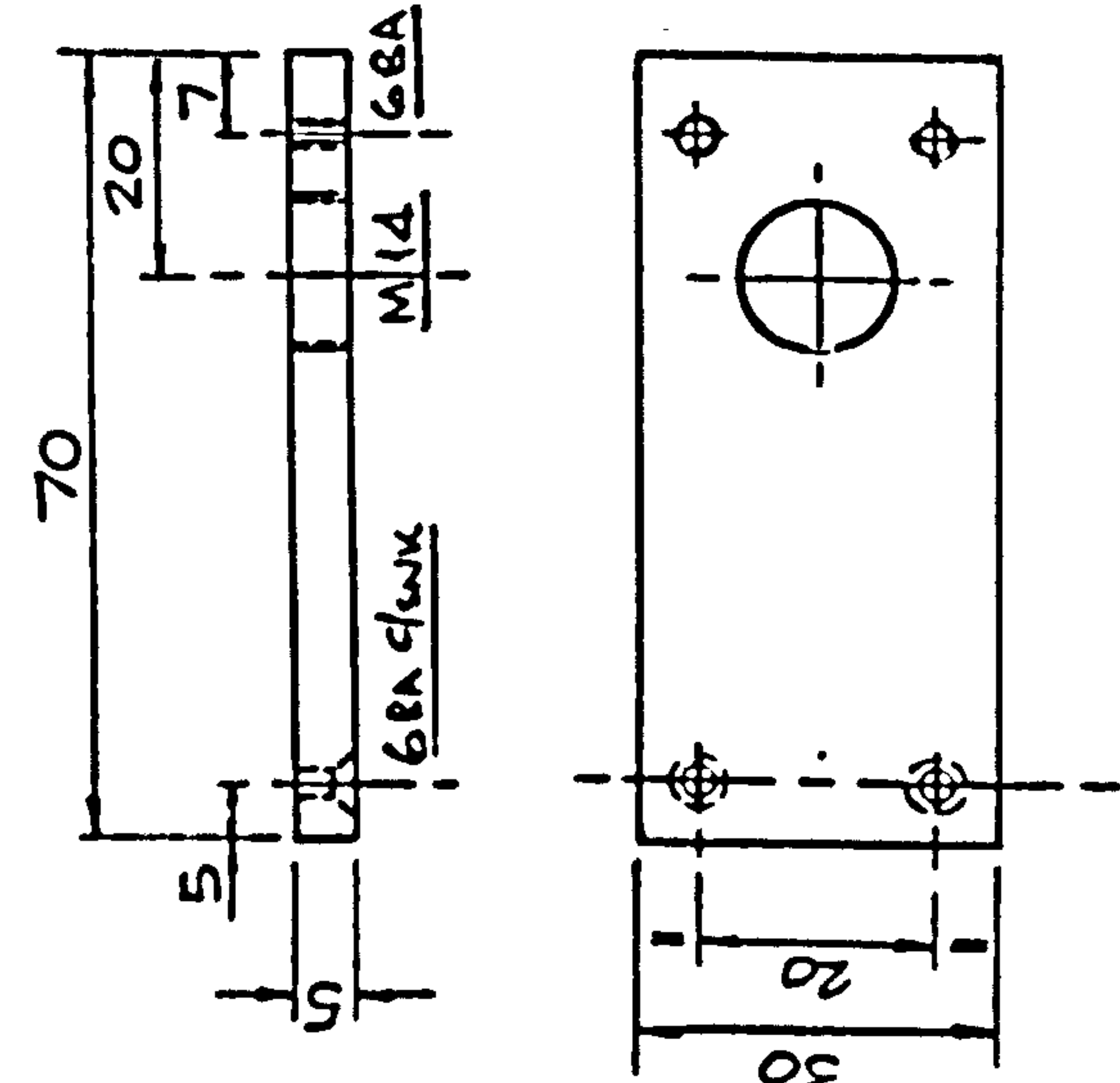
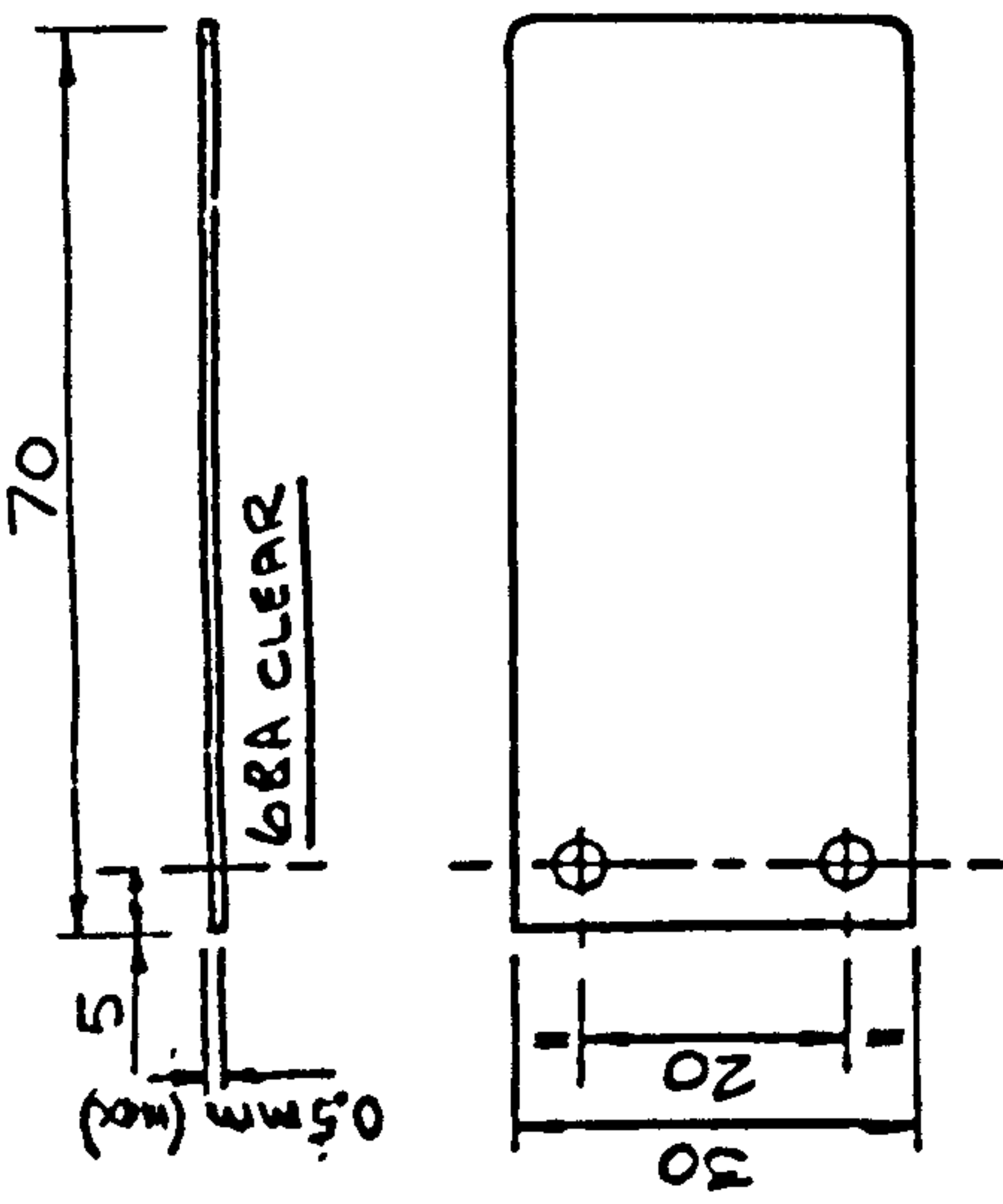
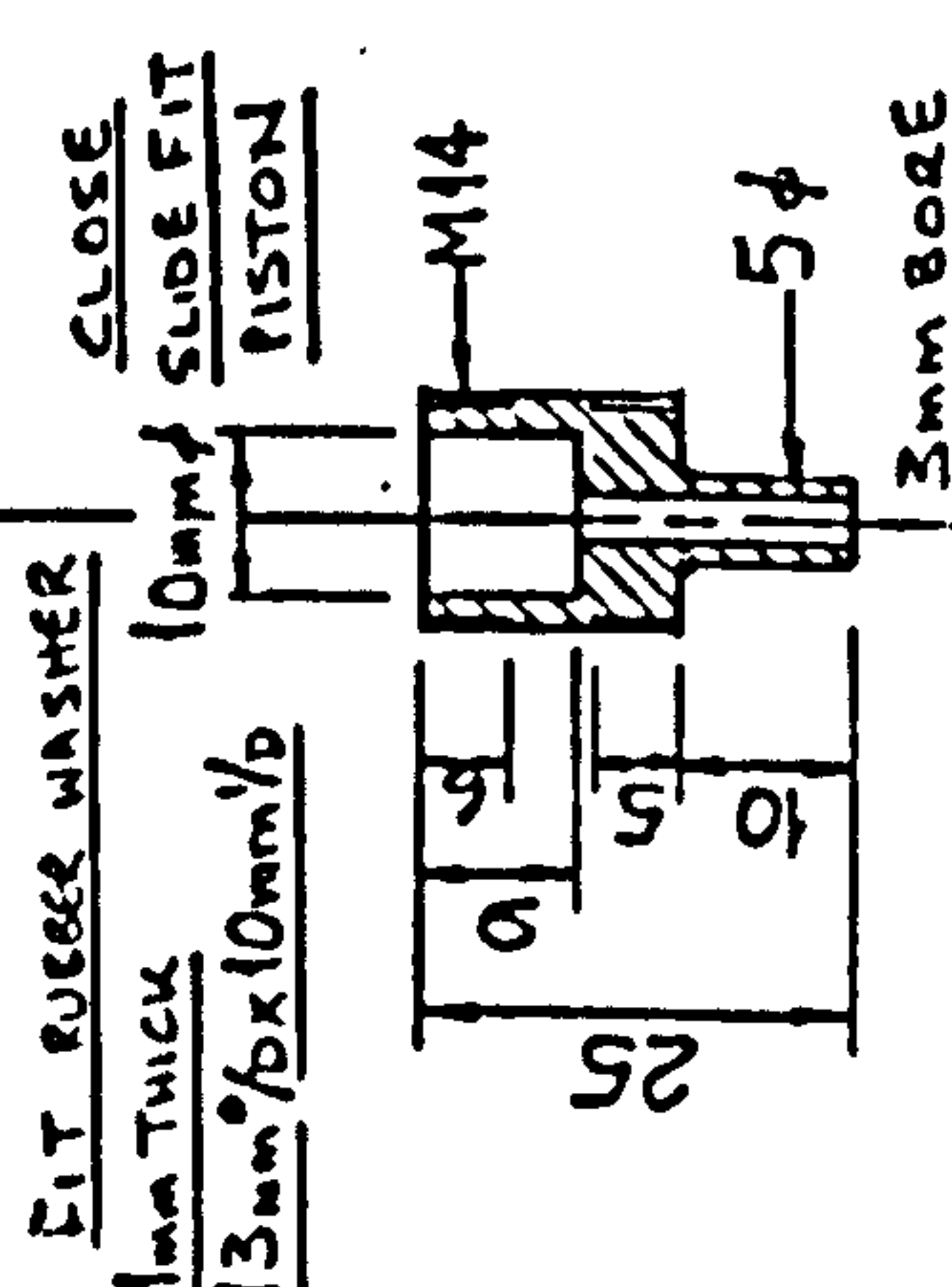
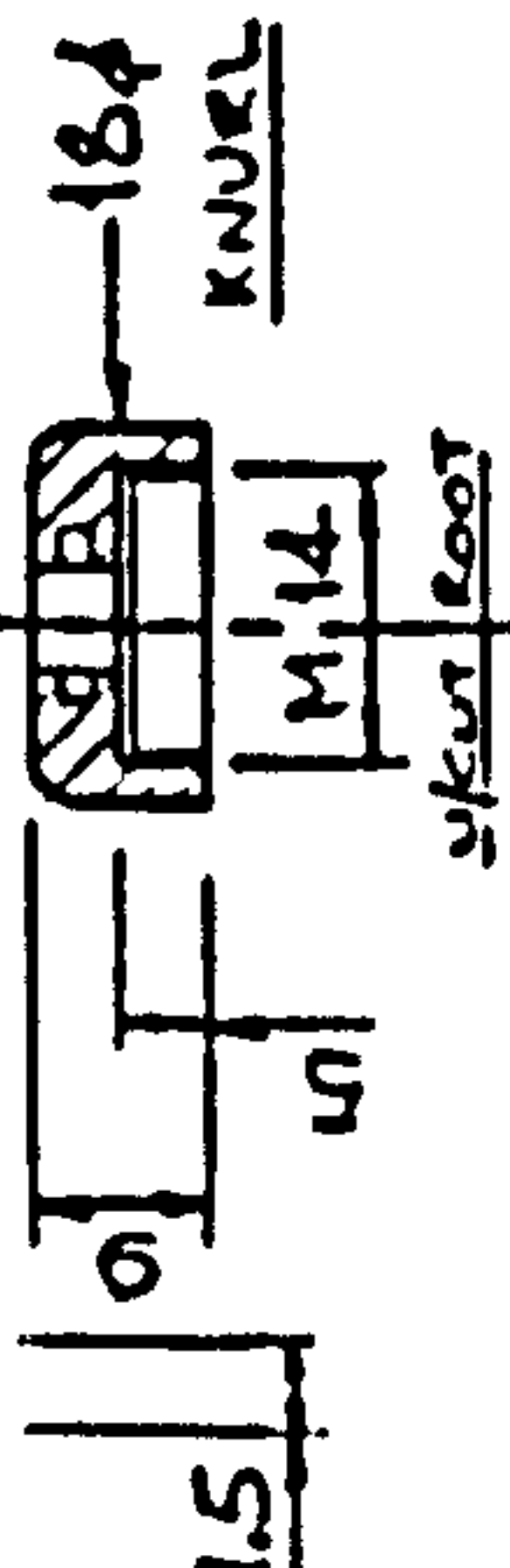
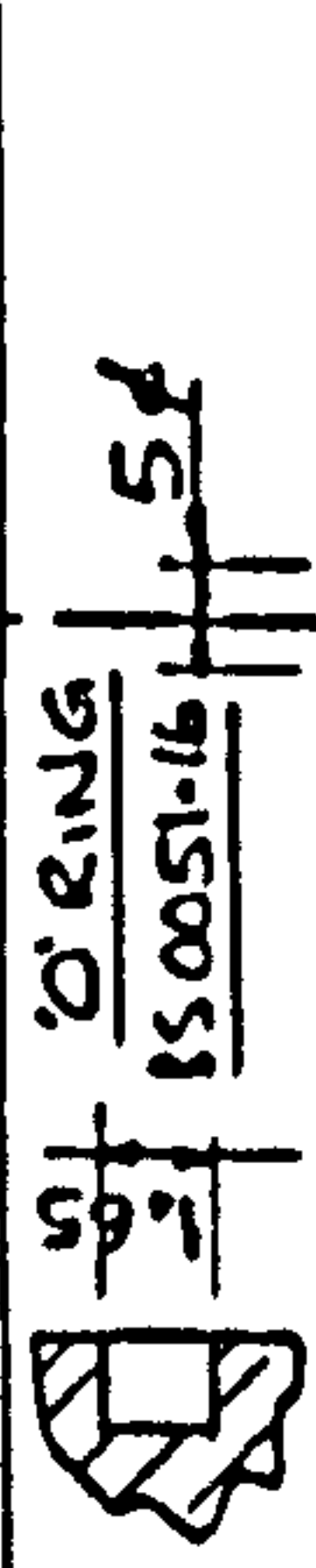
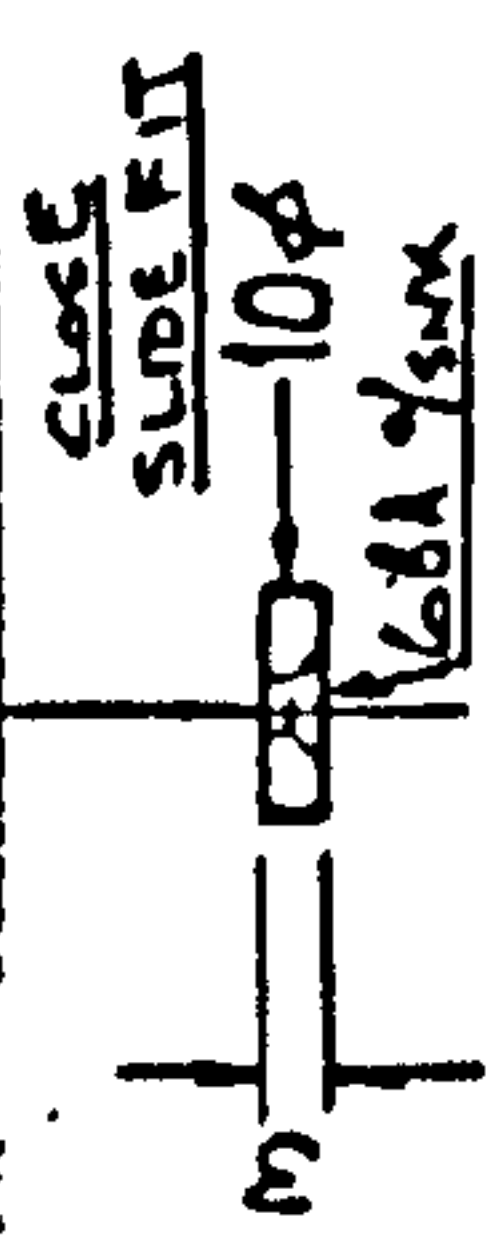
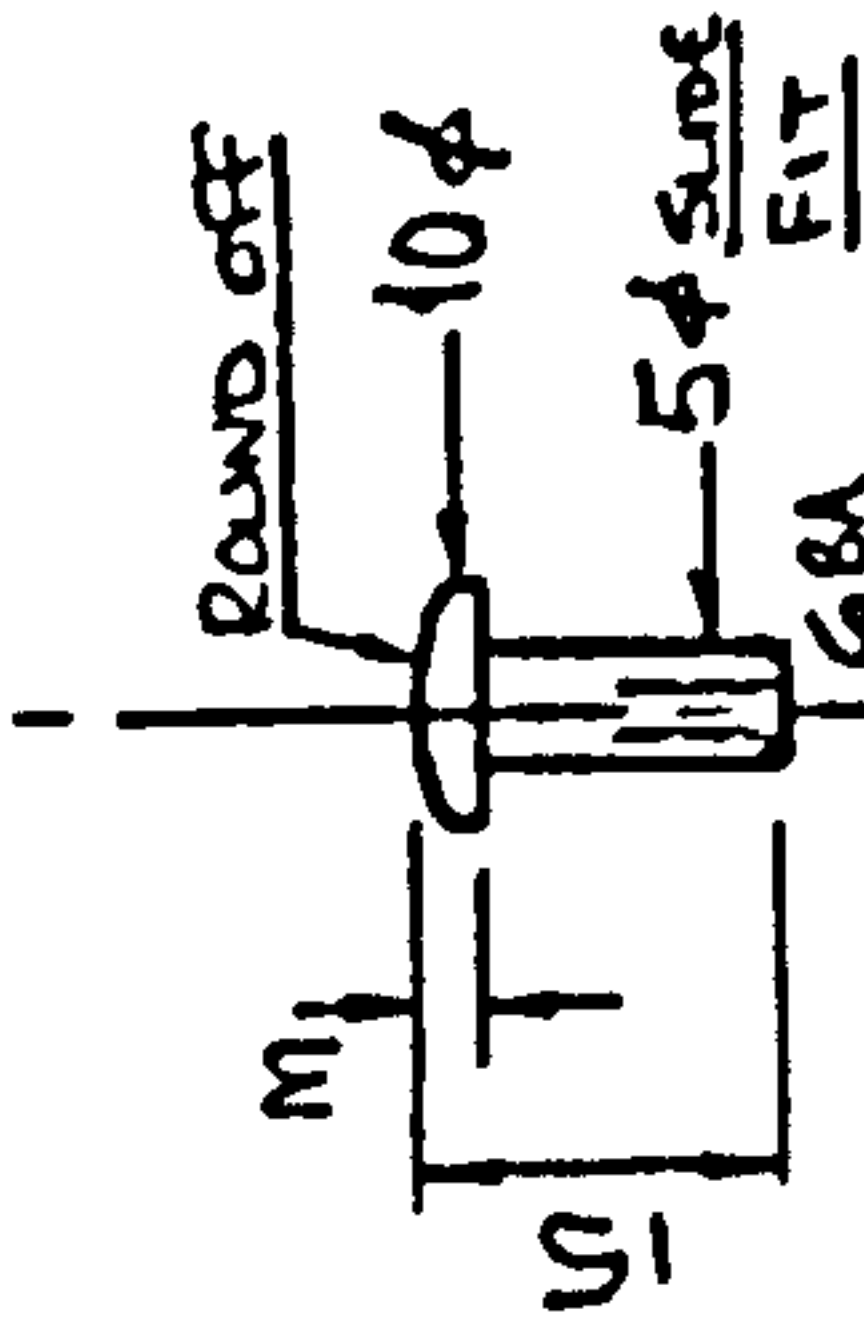
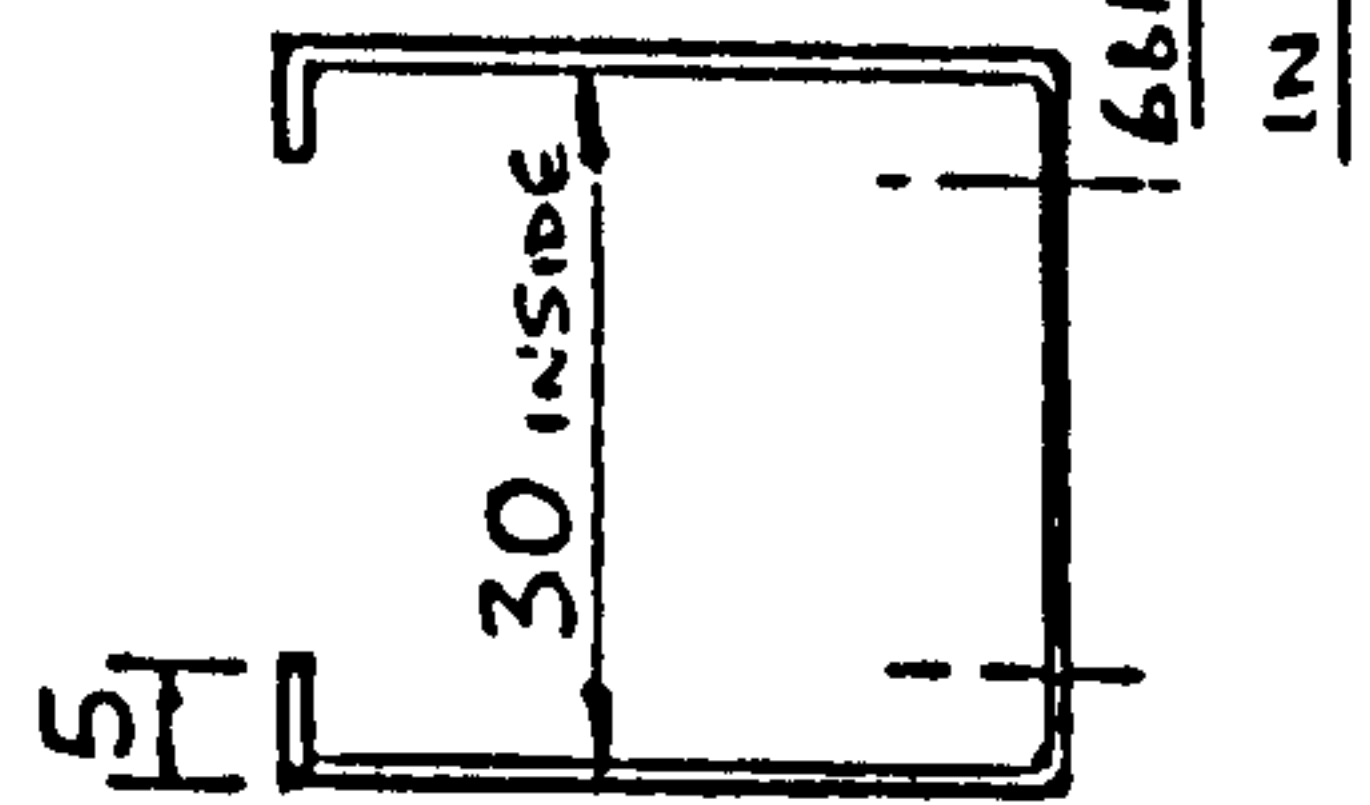
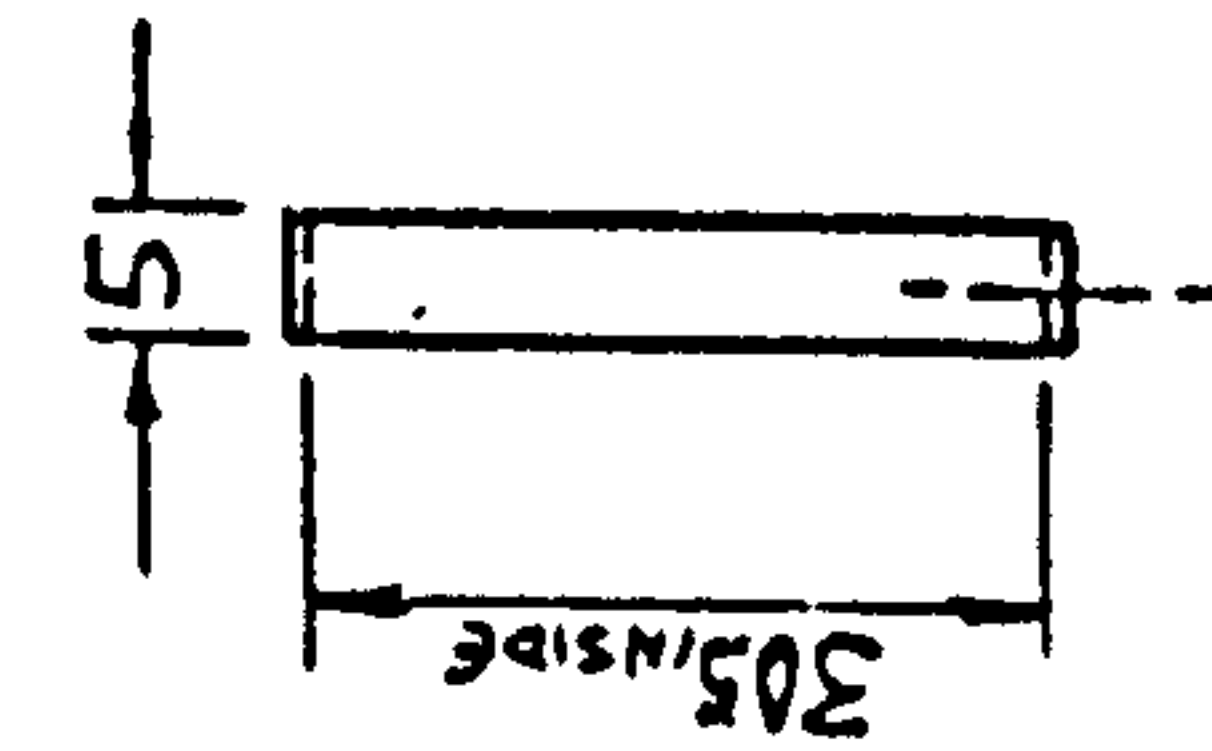
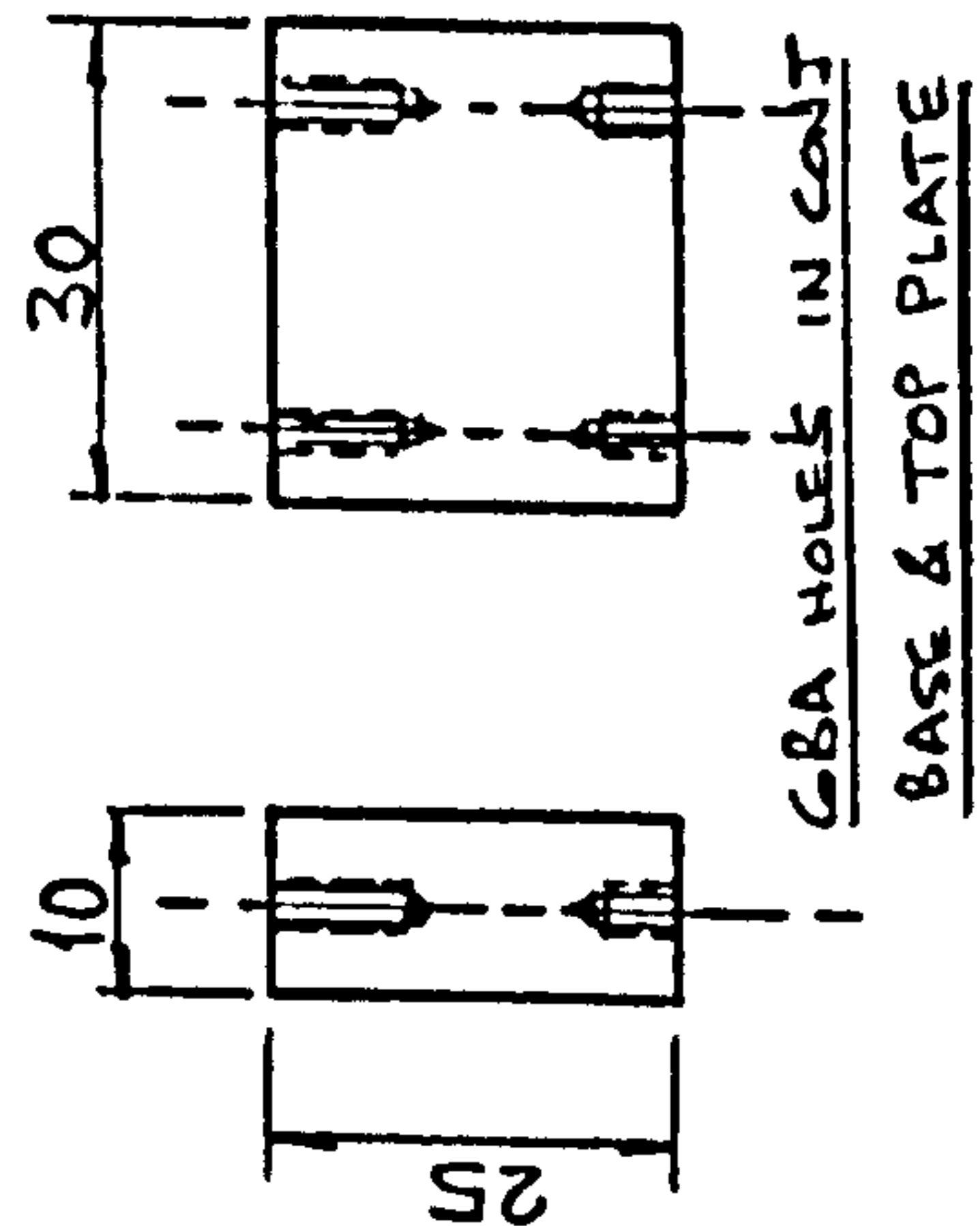
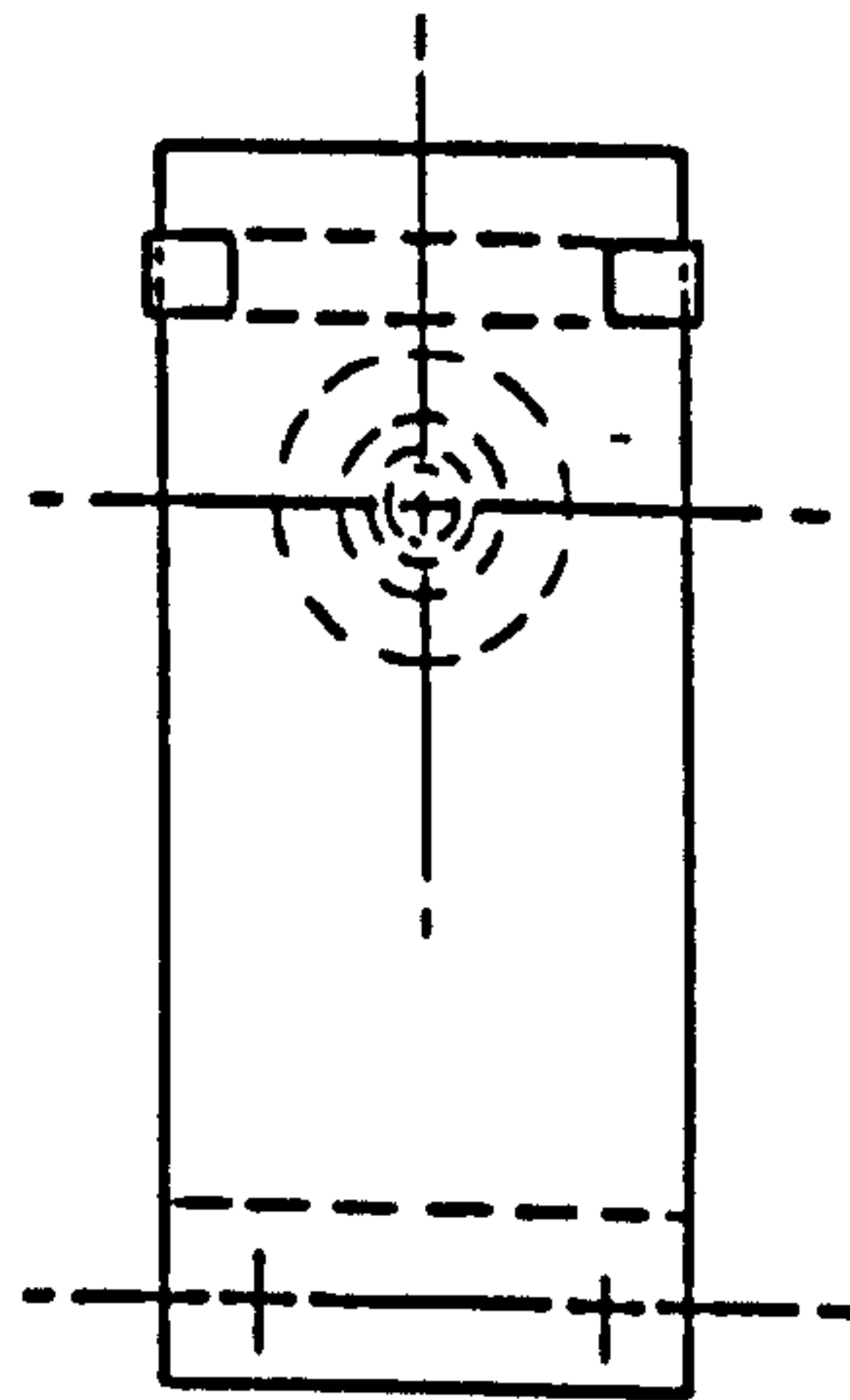
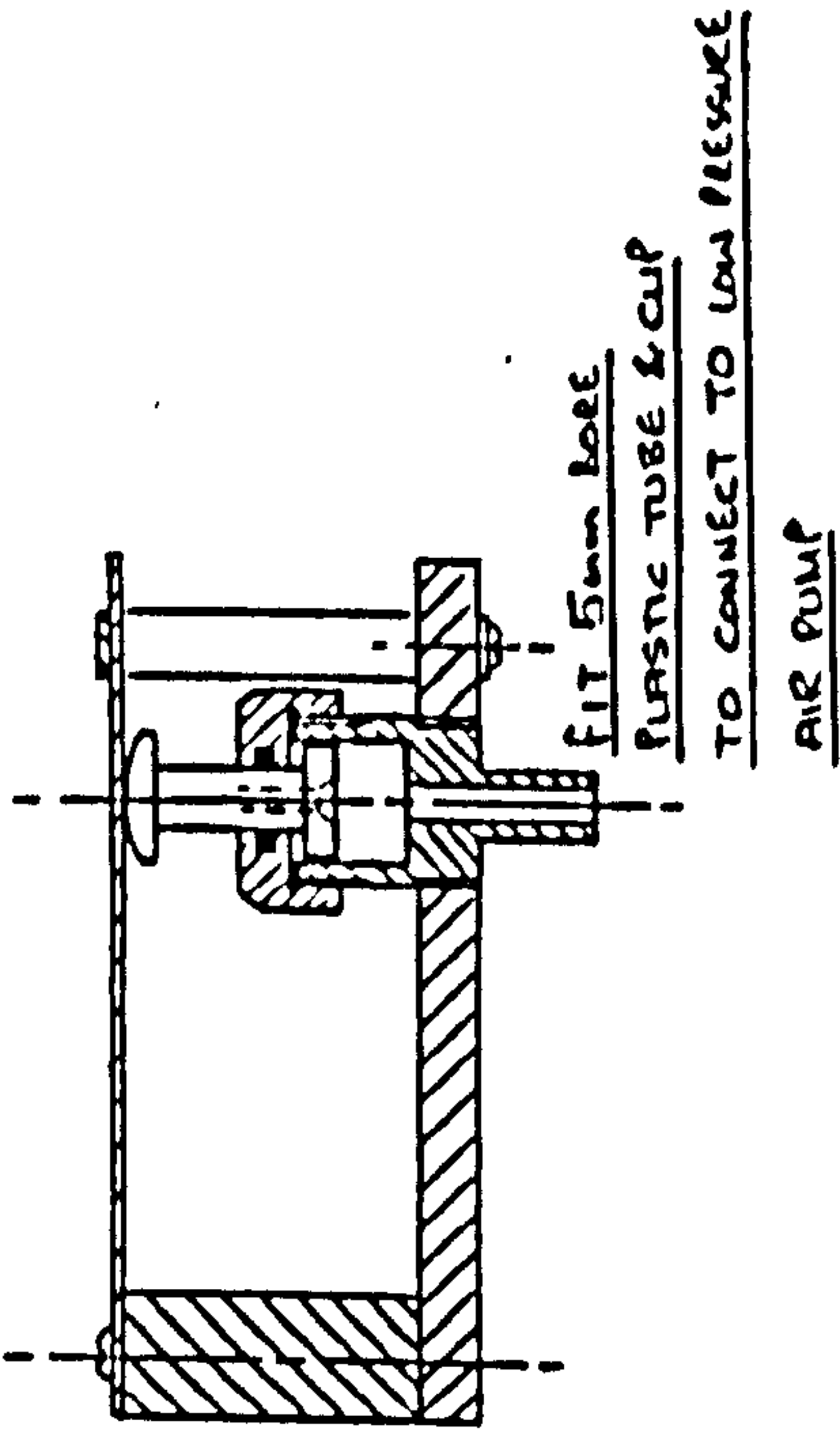


Prototype 2



MAT: ALL STAINLESS STEEL

Prototypes



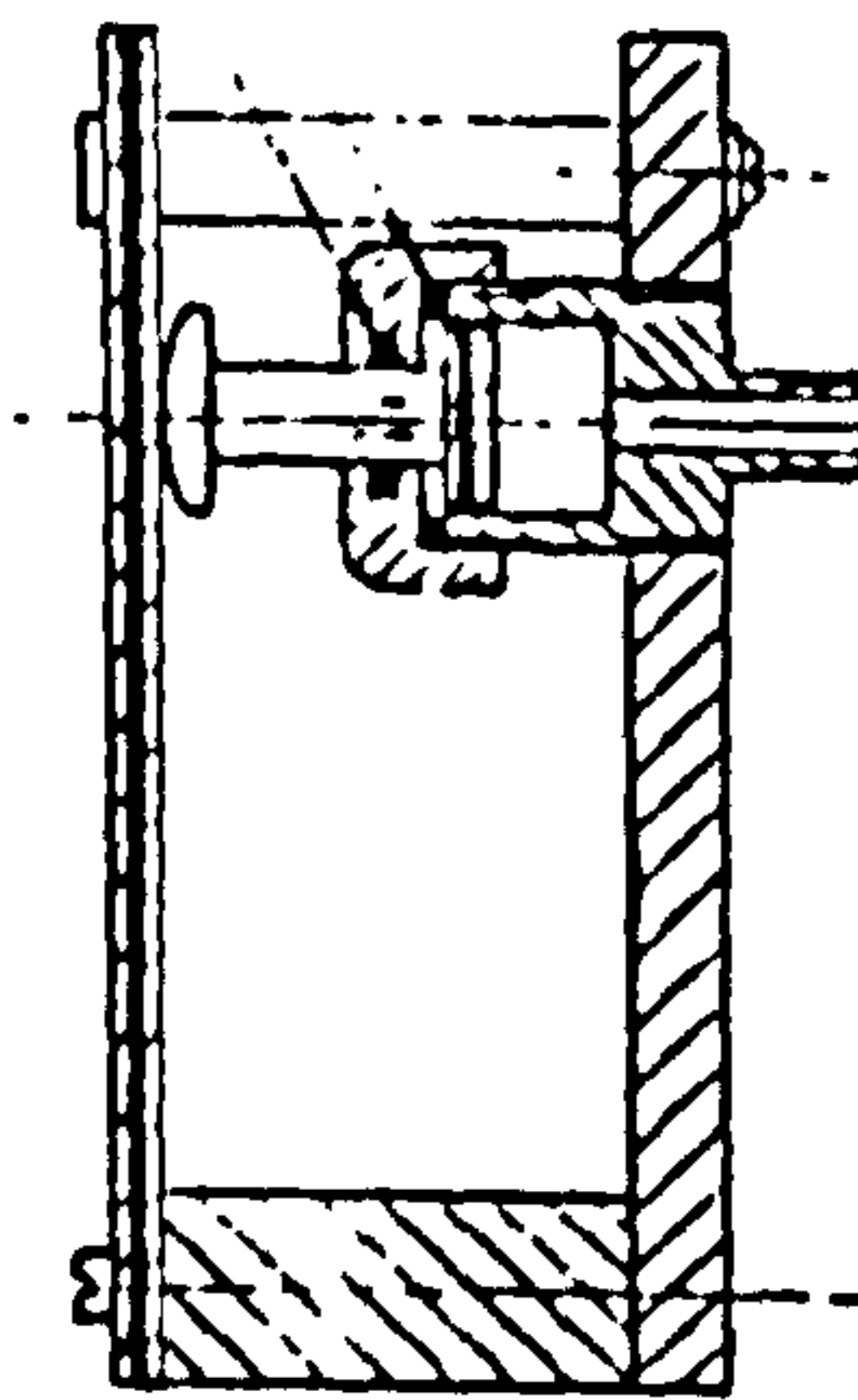
UNIVERSITY OF SALFORD
DEPT. ELECTRONIC & ELECTRICAL ENG.
TITLE: HAND HELD PRESSURE SENSOR

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DATE 7.3.89	SHEET NR 1	GA575
SCALE 1/1		

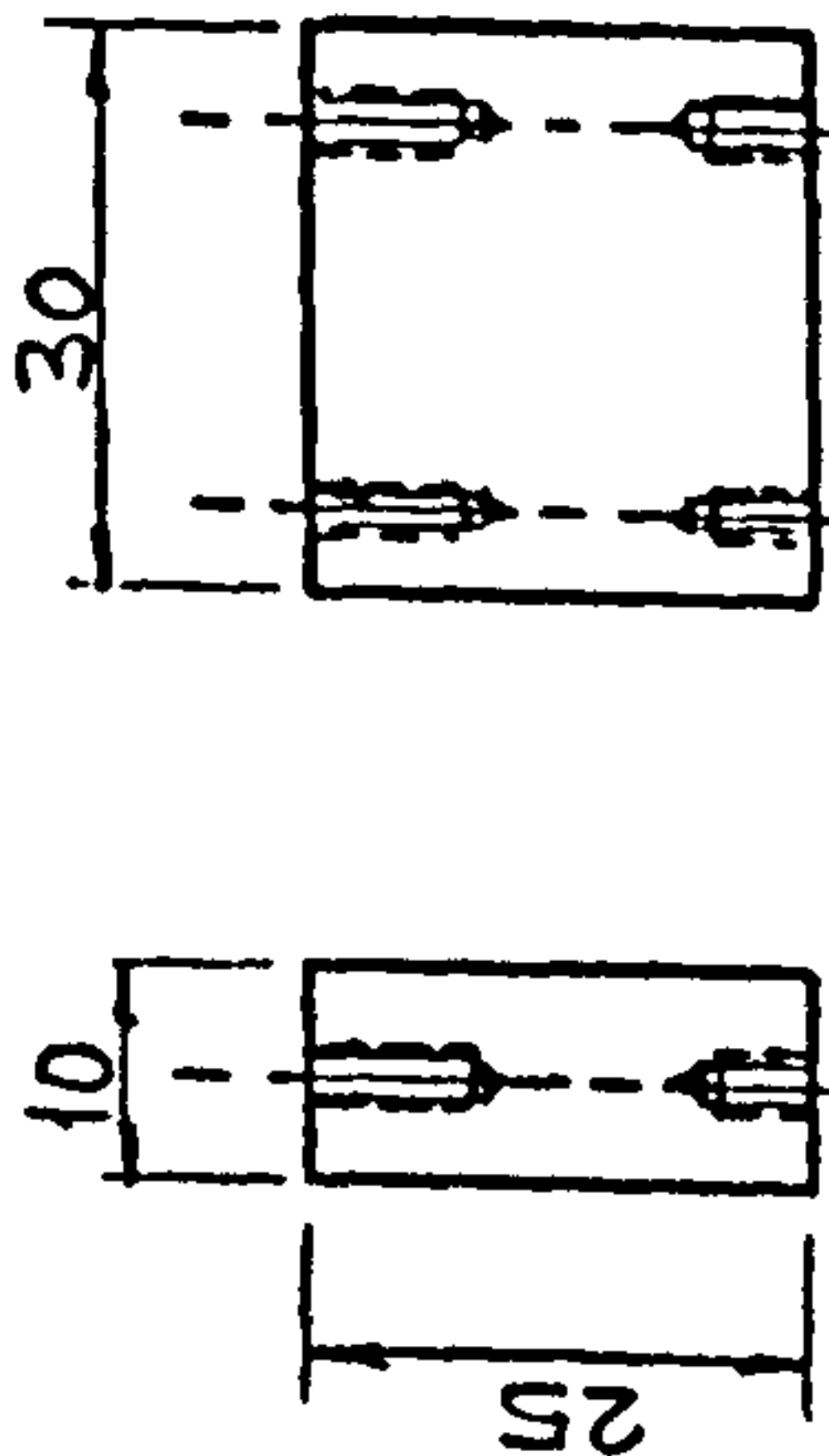
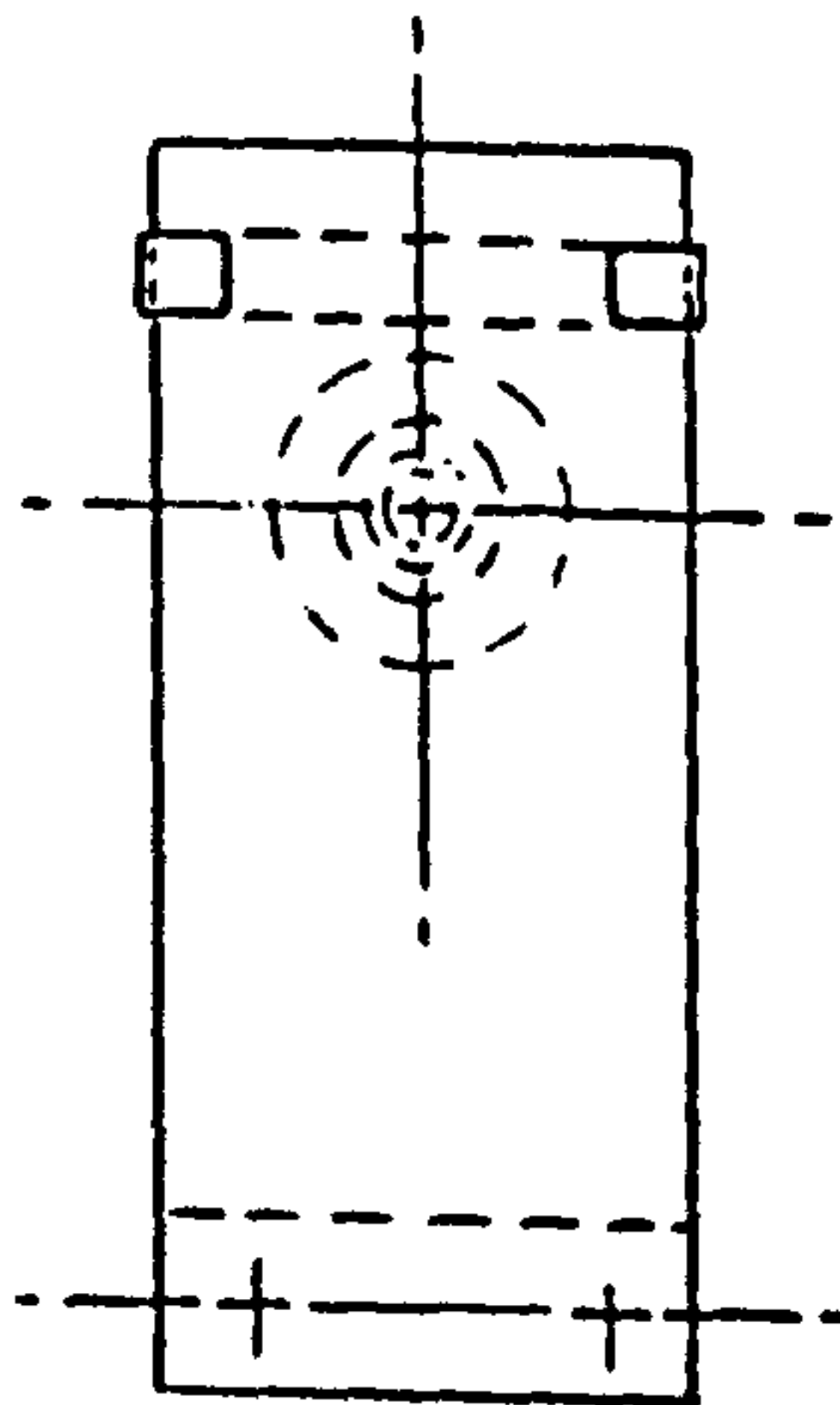
MAT: JUL STAINLESS STEEL

Prototype 4

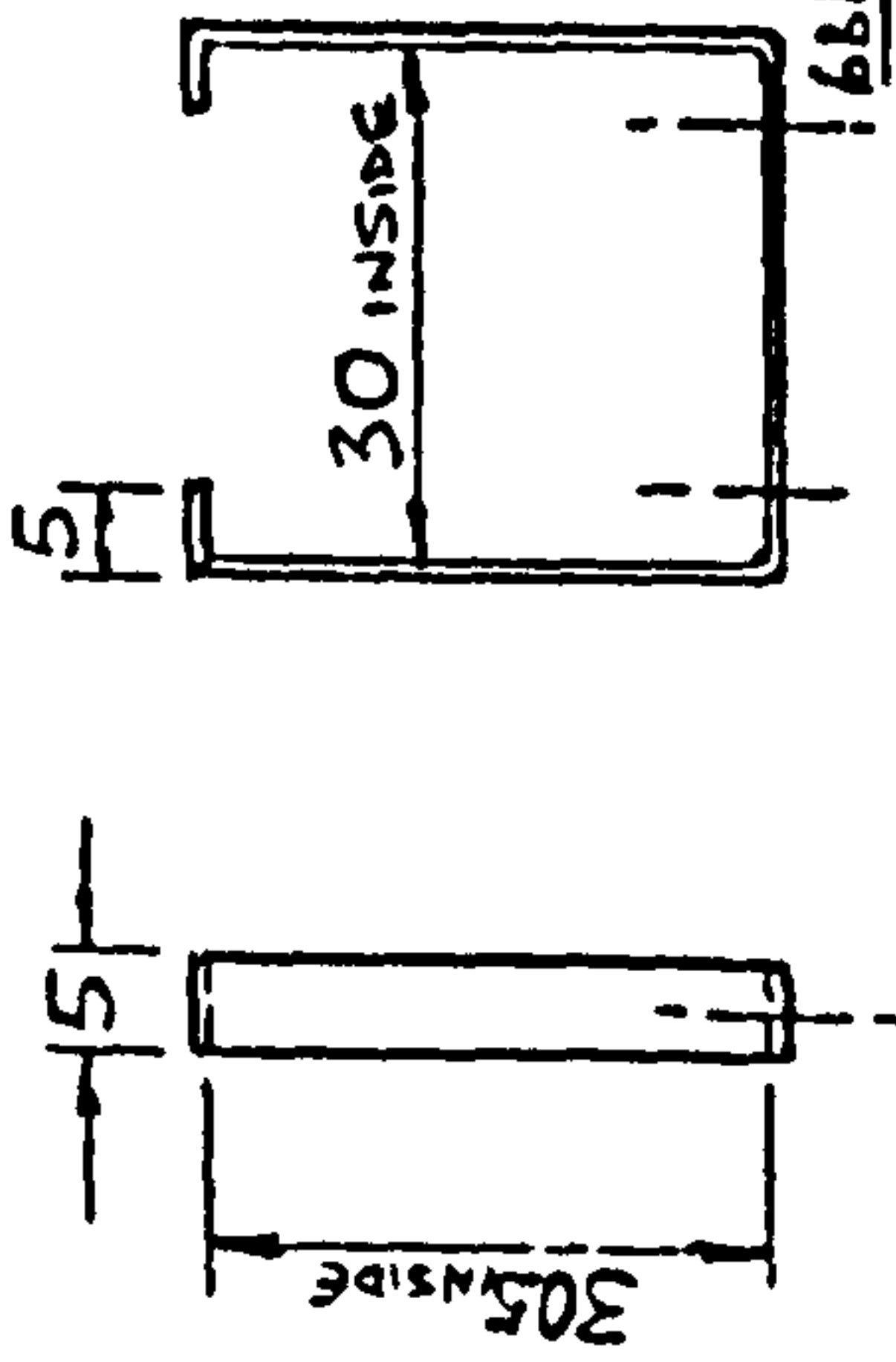
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B5005M-16
B50111-16



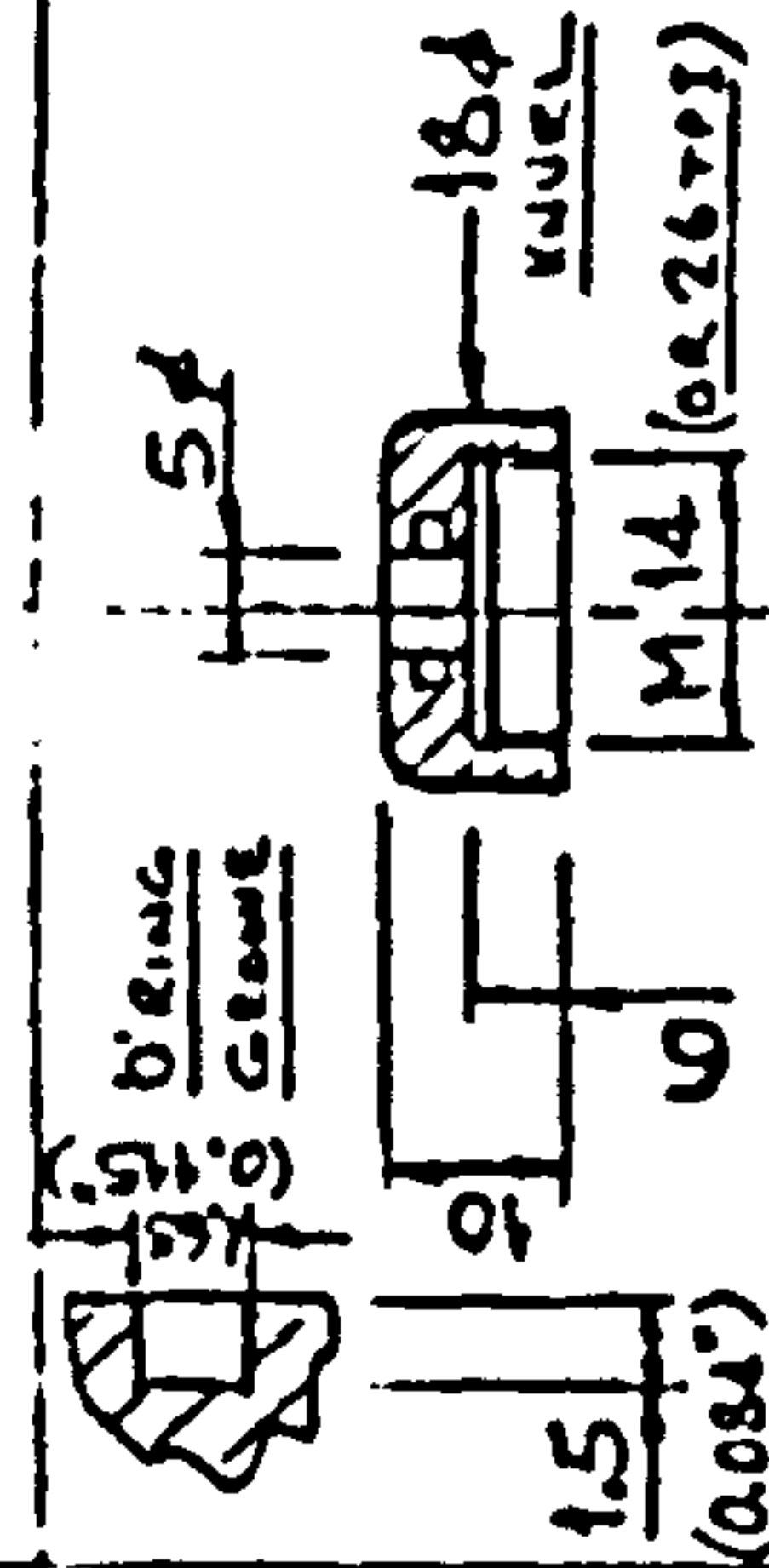
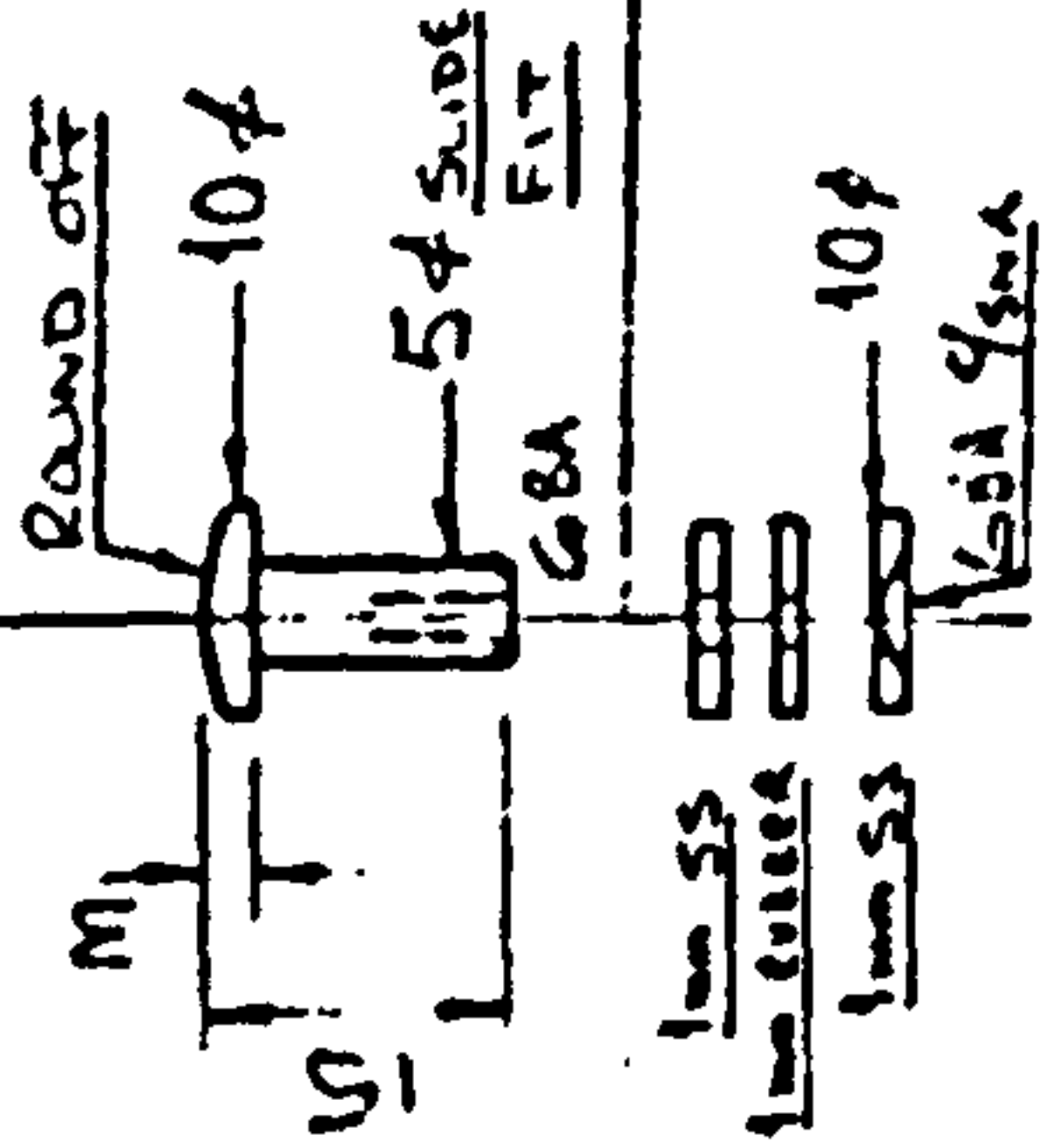
FIT M5
SWAGELOK FITTING
TO CONNECT TO LOW PRESSURE
AIR PUMP



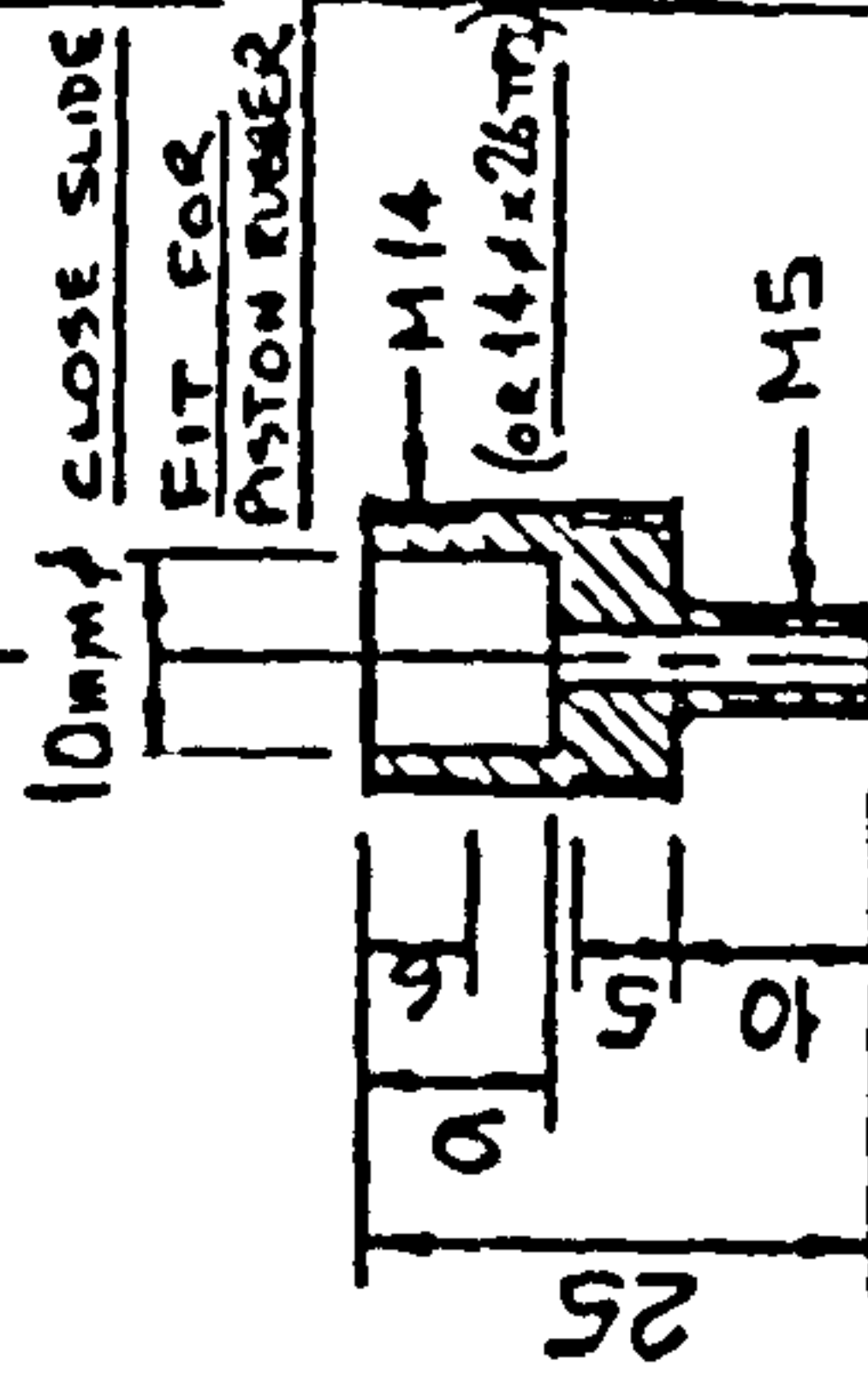
G8A HOLES IN CONT.
BASE & TOP PLATE



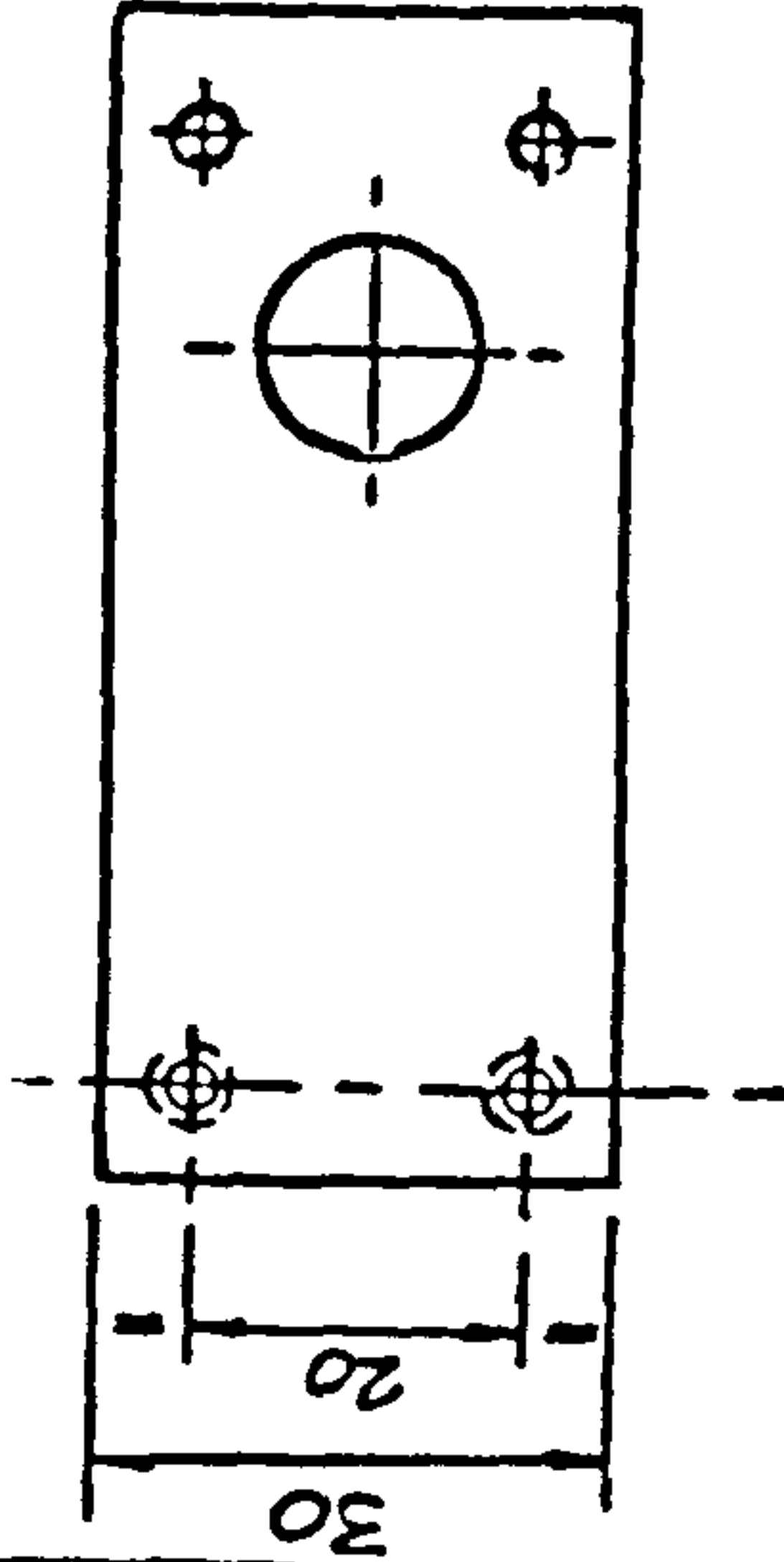
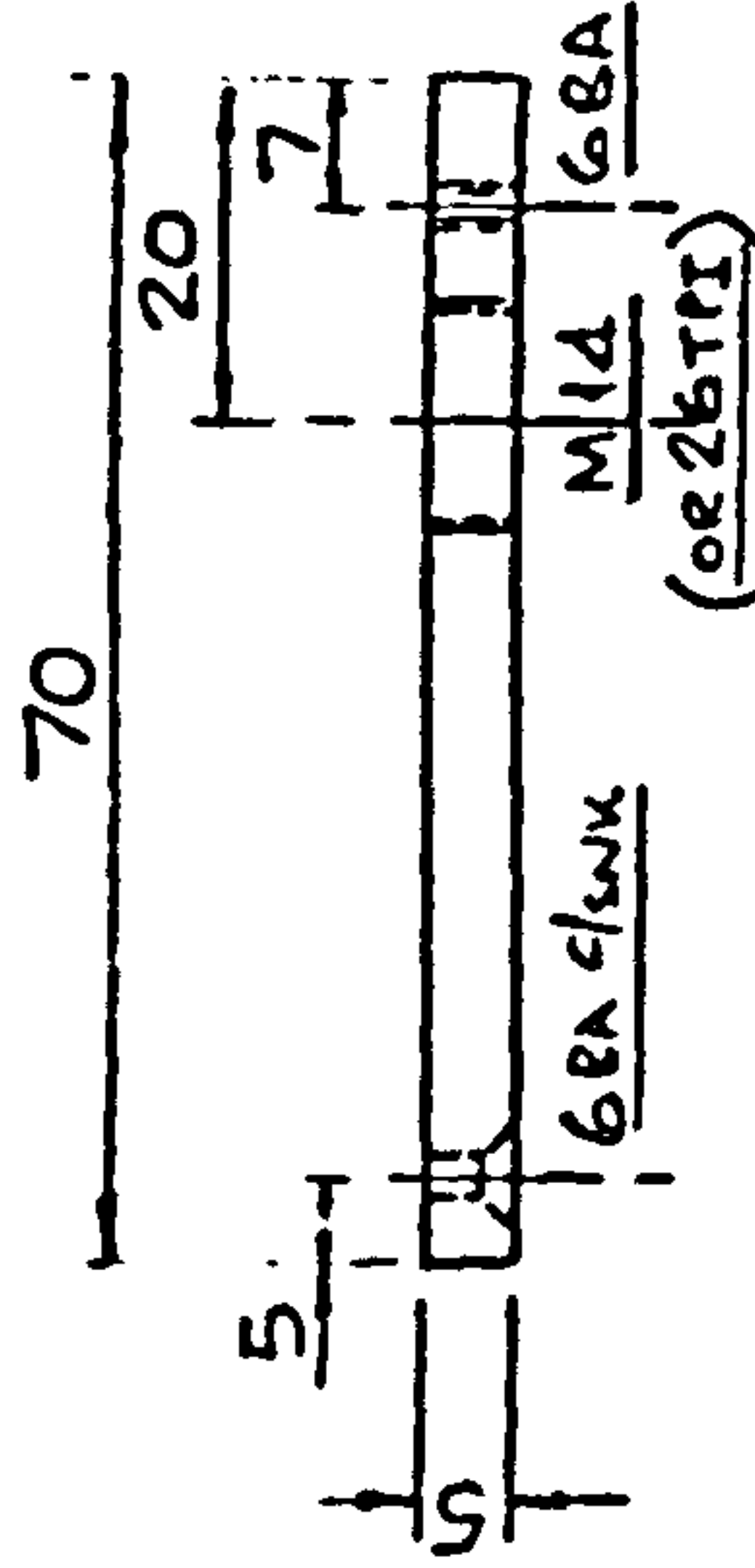
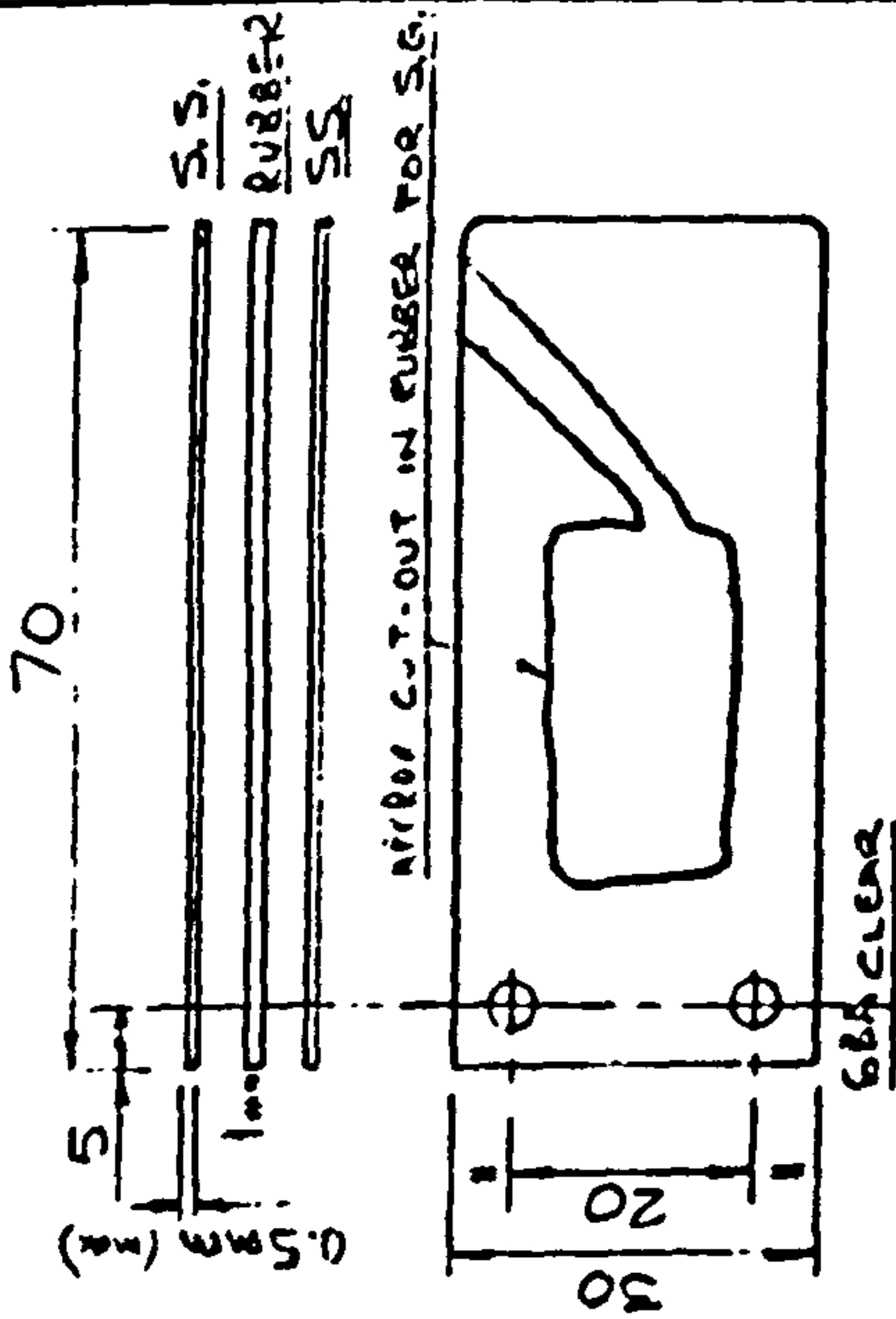
68A CLEAR
IN CONT. BASE



10mm CLOSE SLIDE
FIT FOR
PISTON RUBBER



3mm BORE



UNIVERSITY OF SALFORD			
DEPT. ELECTRONIC & ELECTRICAL ENG.			
TITLE: HAND HEID PRESSURE SENSOR			
DRAWN (CM)	NR OF SHEETS	DRAWING NR	
DATE 7-3-89	SHEET NR 1	GA575	
ISSUE 1/2	SCALE 1/1		

APPENDIX 2

Shows the HBM amplifier circuit

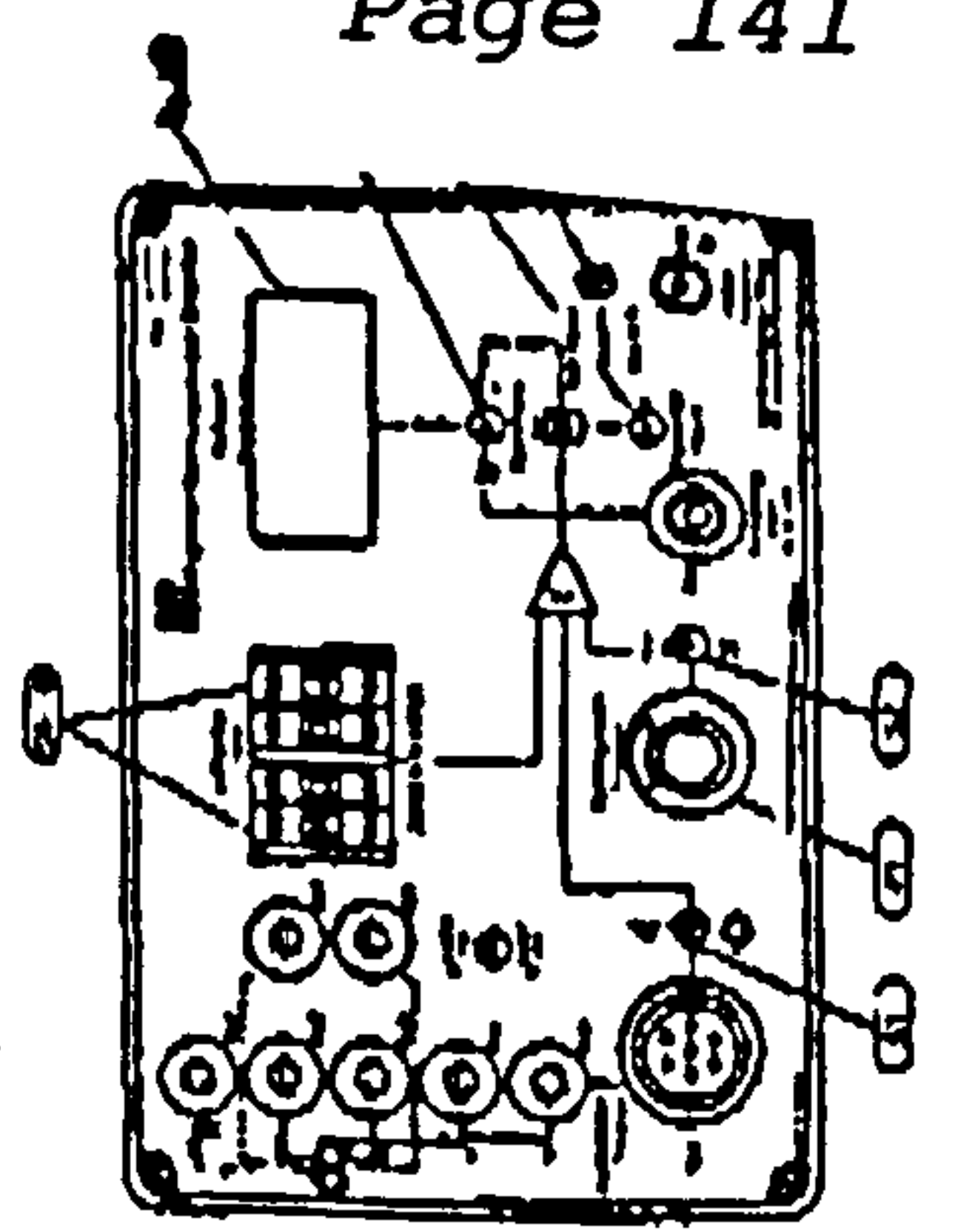
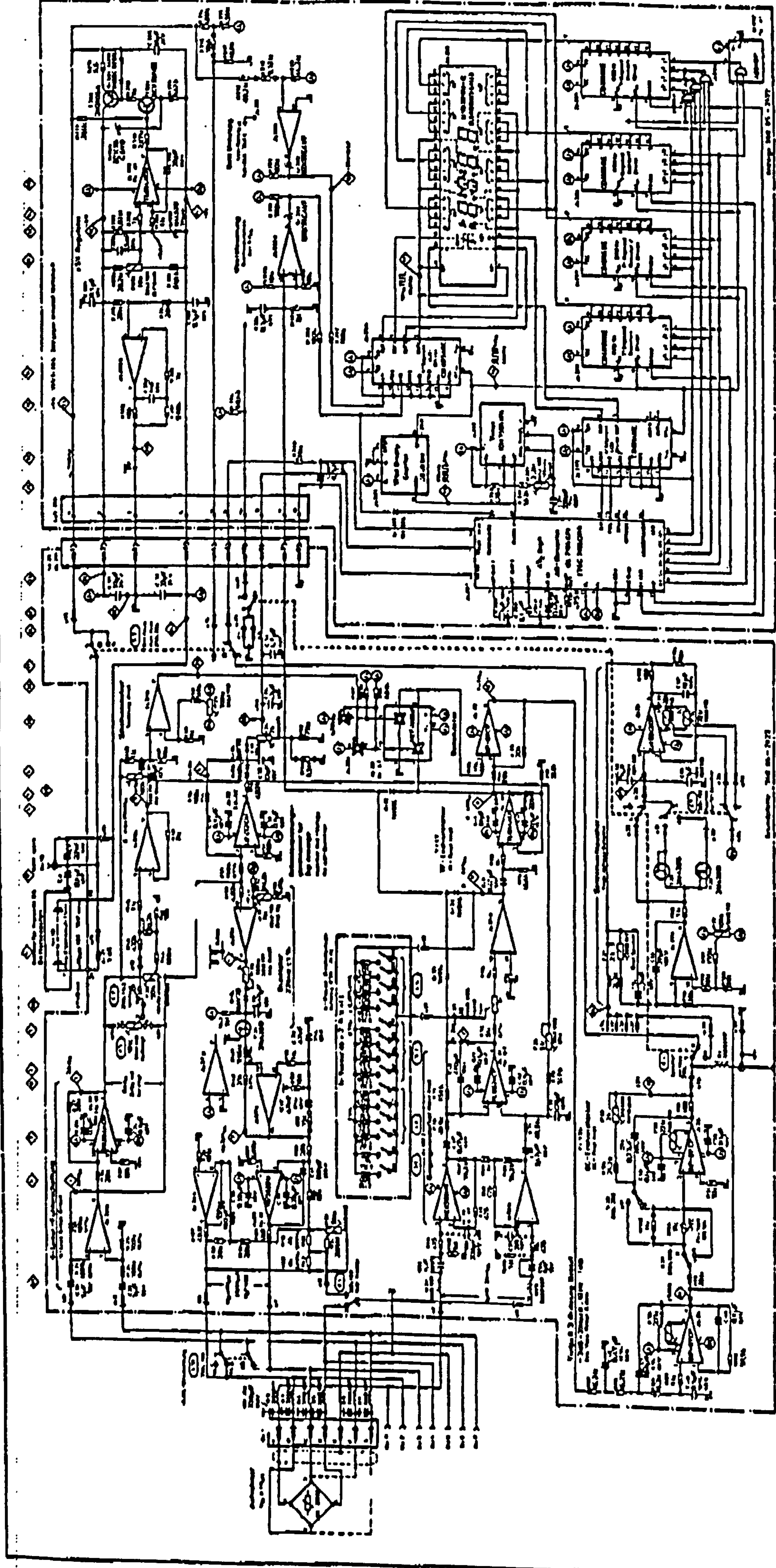
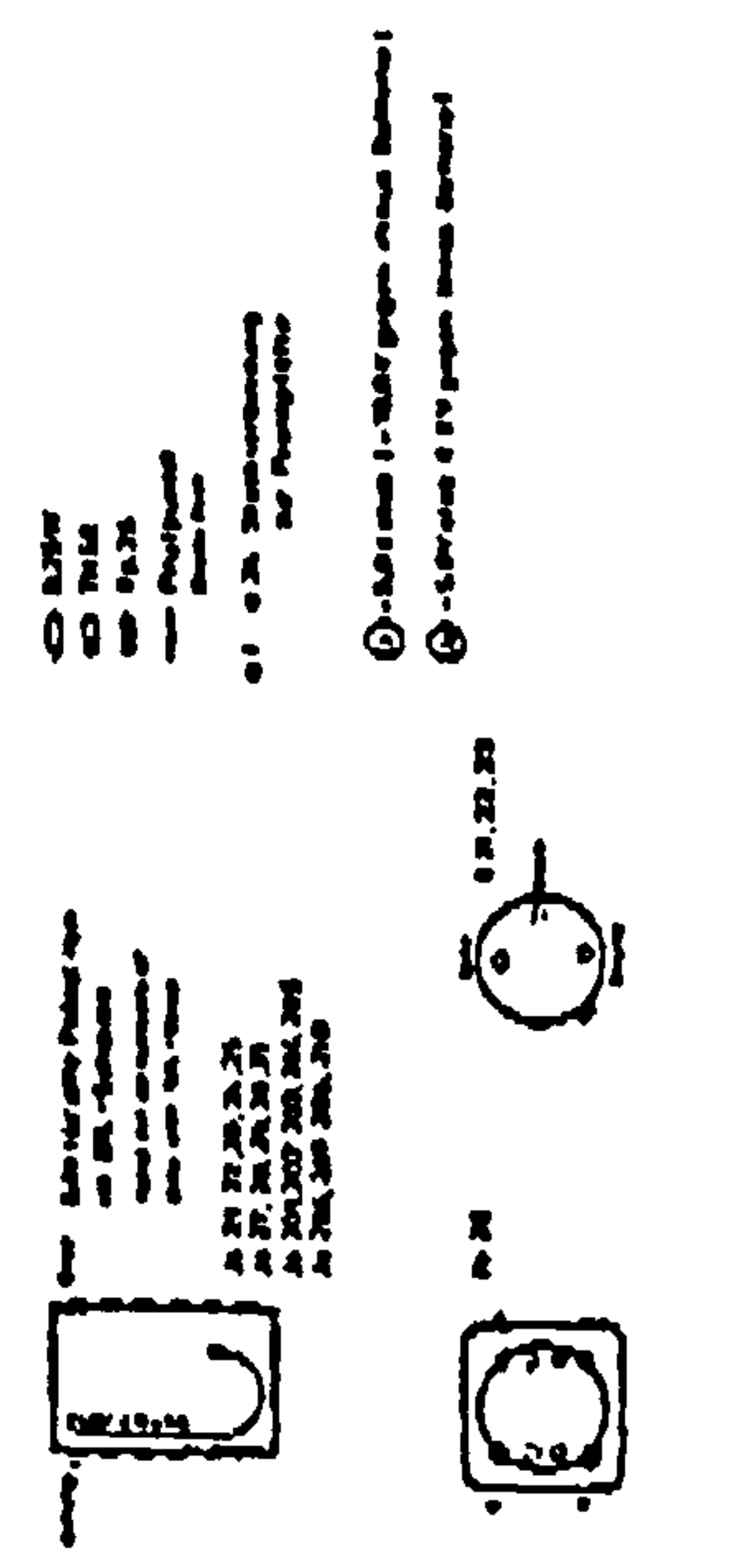
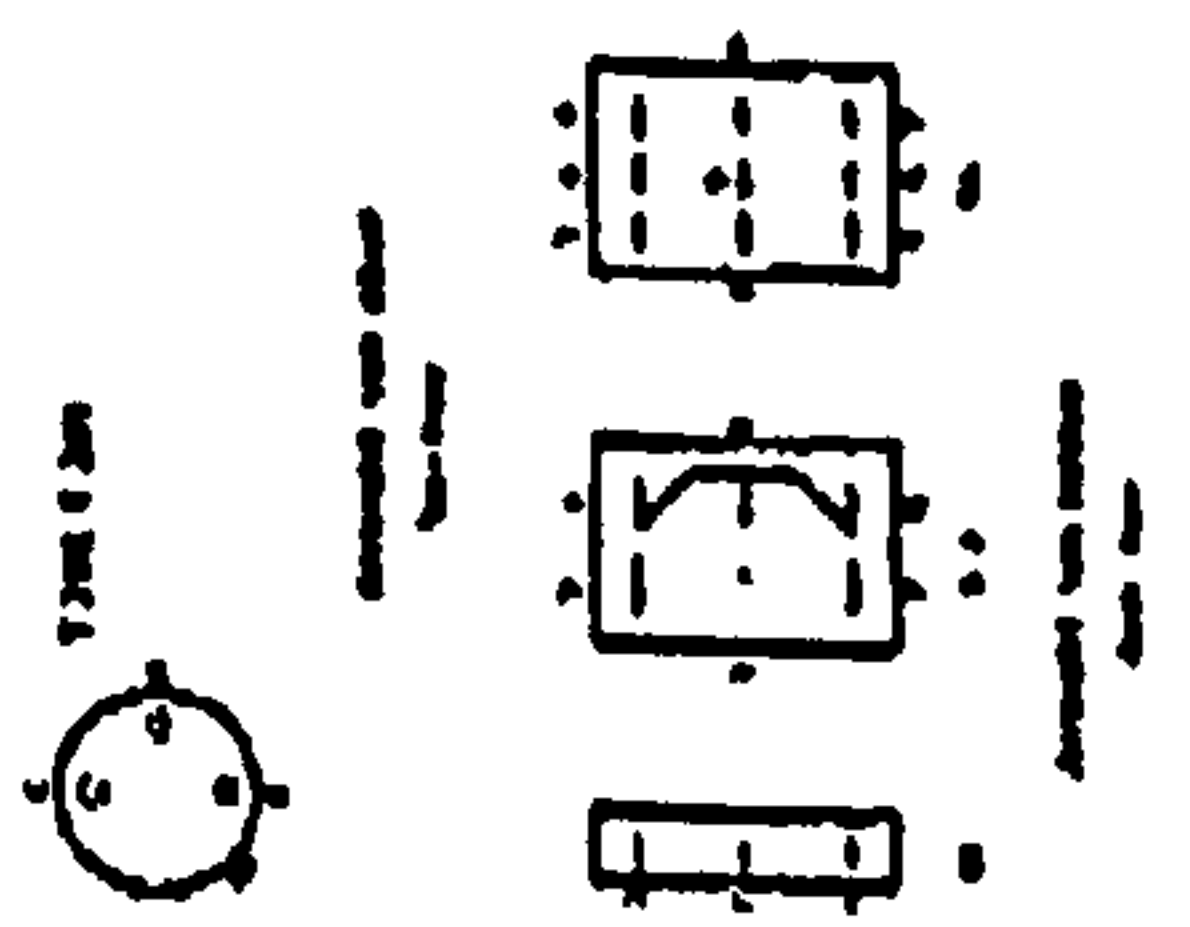


TABLE 1
Component List

QTY	REF. DESIG.	DESCRIPTION	MANUFACTURER
1	Q1	Transistor	...
1	Q2	Transistor	...
1	Q3	Transistor	...
1	Q4	Transistor	...
1	Q5	Transistor	...
1	Q6	Transistor	...
1	Q7	Transistor	...
1	Q8	Transistor	...
1	Q9	Transistor	...
1	Q10	Transistor	...
1	Q11	Transistor	...
1	Q12	Transistor	...
1	Q13	Transistor	...
1	Q14	Transistor	...
1	Q15	Transistor	...
1	Q16	Transistor	...
1	Q17	Transistor	...
1	Q18	Transistor	...
1	Q19	Transistor	...
1	Q20	Transistor	...
1	Q21	Transistor	...
1	Q22	Transistor	...
1	Q23	Transistor	...
1	Q24	Transistor	...
1	Q25	Transistor	...
1	Q26	Transistor	...
1	Q27	Transistor	...
1	Q28	Transistor	...
1	Q29	Transistor	...
1	Q30	Transistor	...
1	Q31	Transistor	...
1	Q32	Transistor	...
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1	Q35	Transistor	...
1	Q36	Transistor	...
1	Q37	Transistor	...
1	Q38	Transistor	...
1	Q39	Transistor	...
1	Q40	Transistor	...
1	Q41	Transistor	...
1	Q42	Transistor	...
1	Q43	Transistor	...
1	Q44	Transistor	...
1	Q45	Transistor	...
1	Q46	Transistor	...
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1	Q54	Transistor	...
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1	Q75	Transistor	...
1	Q76	Transistor	...
1	Q77	Transistor	...
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1	Q80	Transistor	...
1	Q81	Transistor	...
1	Q82	Transistor	...
1	Q83	Transistor	...
1	Q84	Transistor	...
1	Q85	Transistor	...
1	Q86	Transistor	...
1	Q87	Transistor	...
1	Q88	Transistor	...
1	Q89	Transistor	...
1	Q90	Transistor	...
1	Q91	Transistor	...
1	Q92	Transistor	...
1	Q93	Transistor	...
1	Q94	Transistor	...
1	Q95	Transistor	...
1	Q96	Transistor	...
1	Q97	Transistor	...
1	Q98	Transistor	...
1	Q99	Transistor	...
1	Q100	Transistor	...



APPENDIX 3

- 1 Shows data sheet of instrumentation amplifier 1NA101 used in the construction of amplifiers 1, 2 and 3.
- 2 Shows data sheet for the R S Amplifier.
- 3 Shows data sheet for LCD.
- 4 Shows data sheet for A/D converter

R.S. 636-227

£7.20

1-



INA101

Very-High Accuracy INSTRUMENTATION AMPLIFIER

FEATURES

- ULTRA-LOW VOLTAGE DRIFT - $0.25 \mu\text{V}/^\circ\text{C}$
- LOW OFFSET VOLTAGE - $25 \mu\text{V}$
- LOW NONLINEARITY - 0.002%
- LOW NOISE - $13 \text{ nV}/\sqrt{\text{Hz}}$ at $f_0 = 1 \text{ kHz}$
- HIGH CMR - 106 dB at 60 Hz
- HIGH INPUT IMPEDANCE - $10^{10} \Omega$
- LOW COST, TO-100, CERAMIC DIP AND PLASTIC PACKAGE

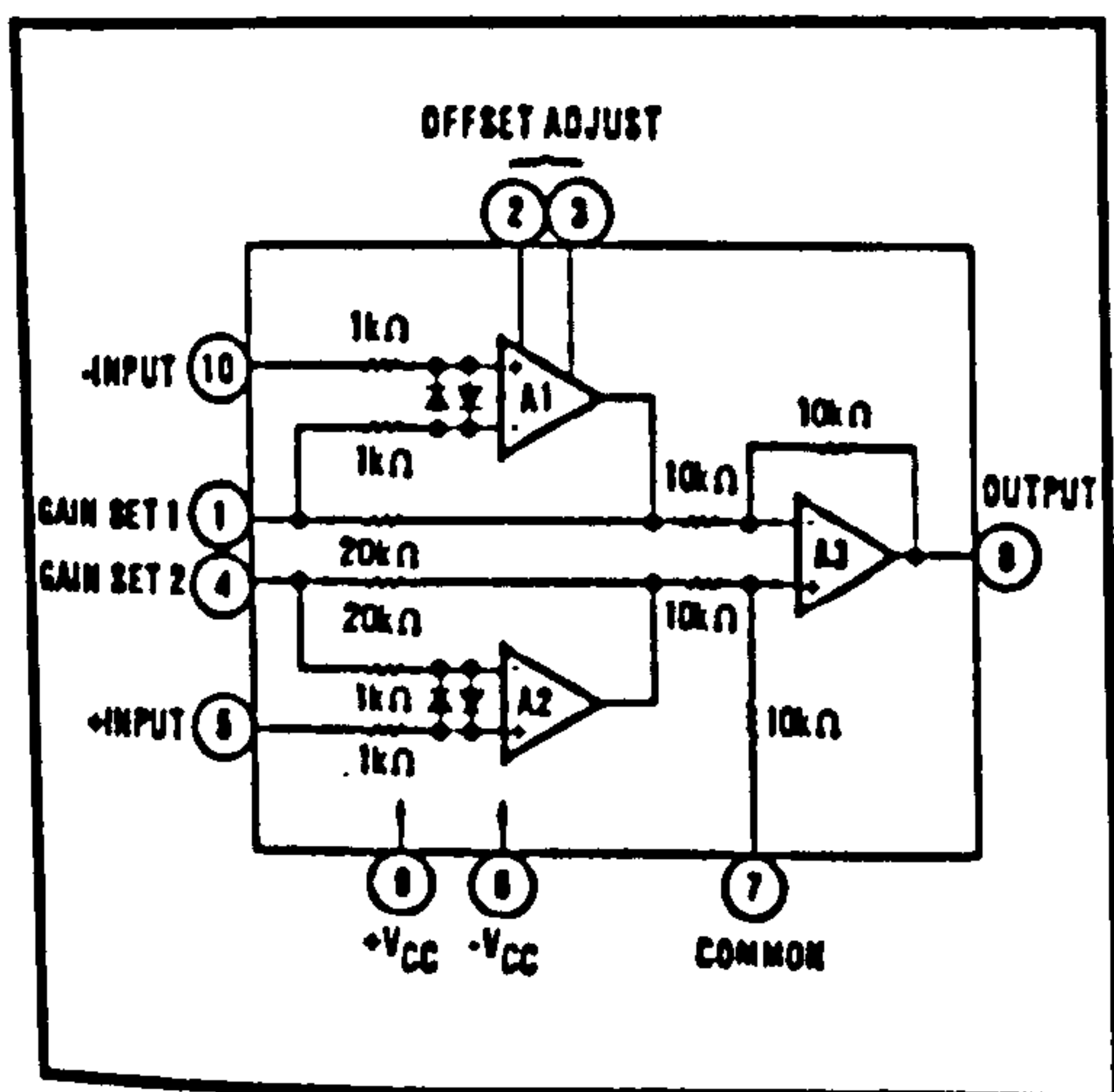
APPLICATIONS

- AMPLIFICATION OF SIGNALS FROM SOURCES SUCH AS:
 - Strain Gages
 - Thermocouples
 - RTDs
- REMOTE TRANSDUCERS
- LOW LEVEL SIGNALS
- MEDICAL INSTRUMENTATION

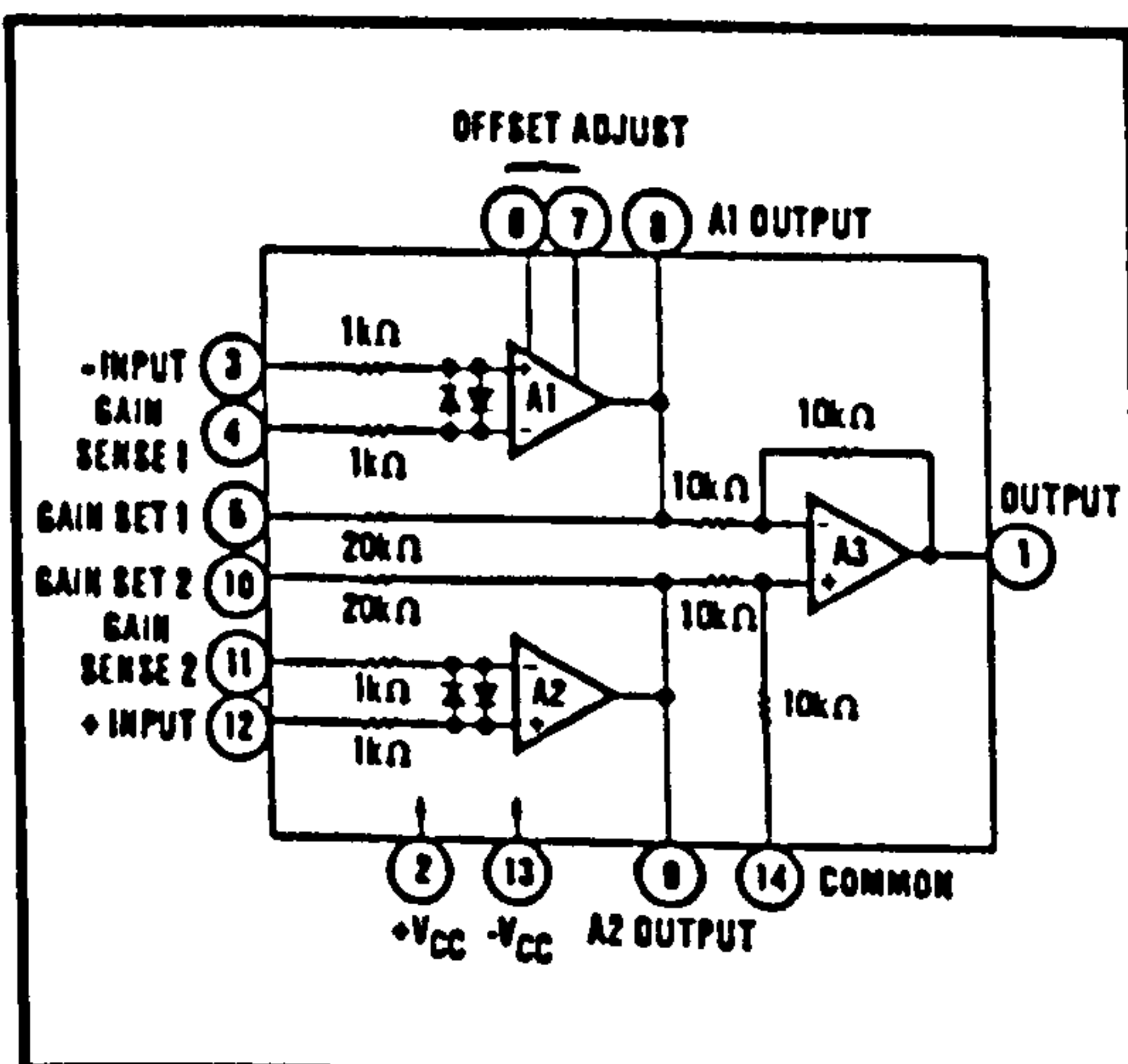
DESCRIPTION

The INA101 is a high accuracy, multistage, integrated-circuit instrumentation amplifier designed for signal conditioning requirements where very-high performance is desired. All circuits, including the interconnected laser-trimmed thin-film resistors, are integrated on a single monolithic substrate.

A multi-amplifier design is used to provide the highest performance and maximum versatility with monolithic construction for low cost. The input stage uses Burr-Brown's ultra-low drift, low noise technology to provide exceptional input characteristics.



M Package



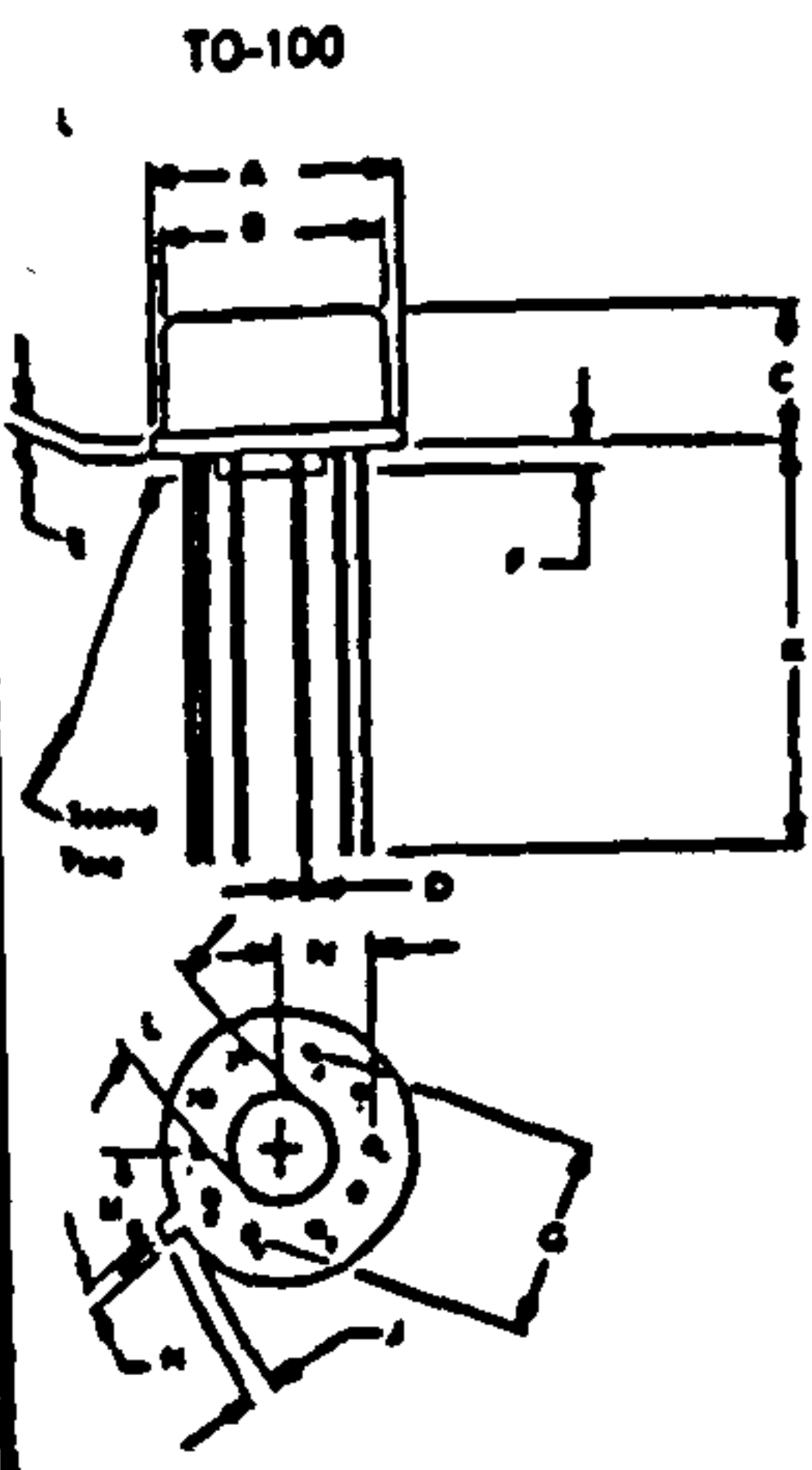
G and P Packages

International Airport Industrial Park - P.O. Box 11400 - Tucson, Arizona 85734 - Tel. (602) 746-1111 - Twx: 910-952-1111 - Cable: BURCORP - Telex: 66-6491

PDS-454F

MECHANICAL

M Package

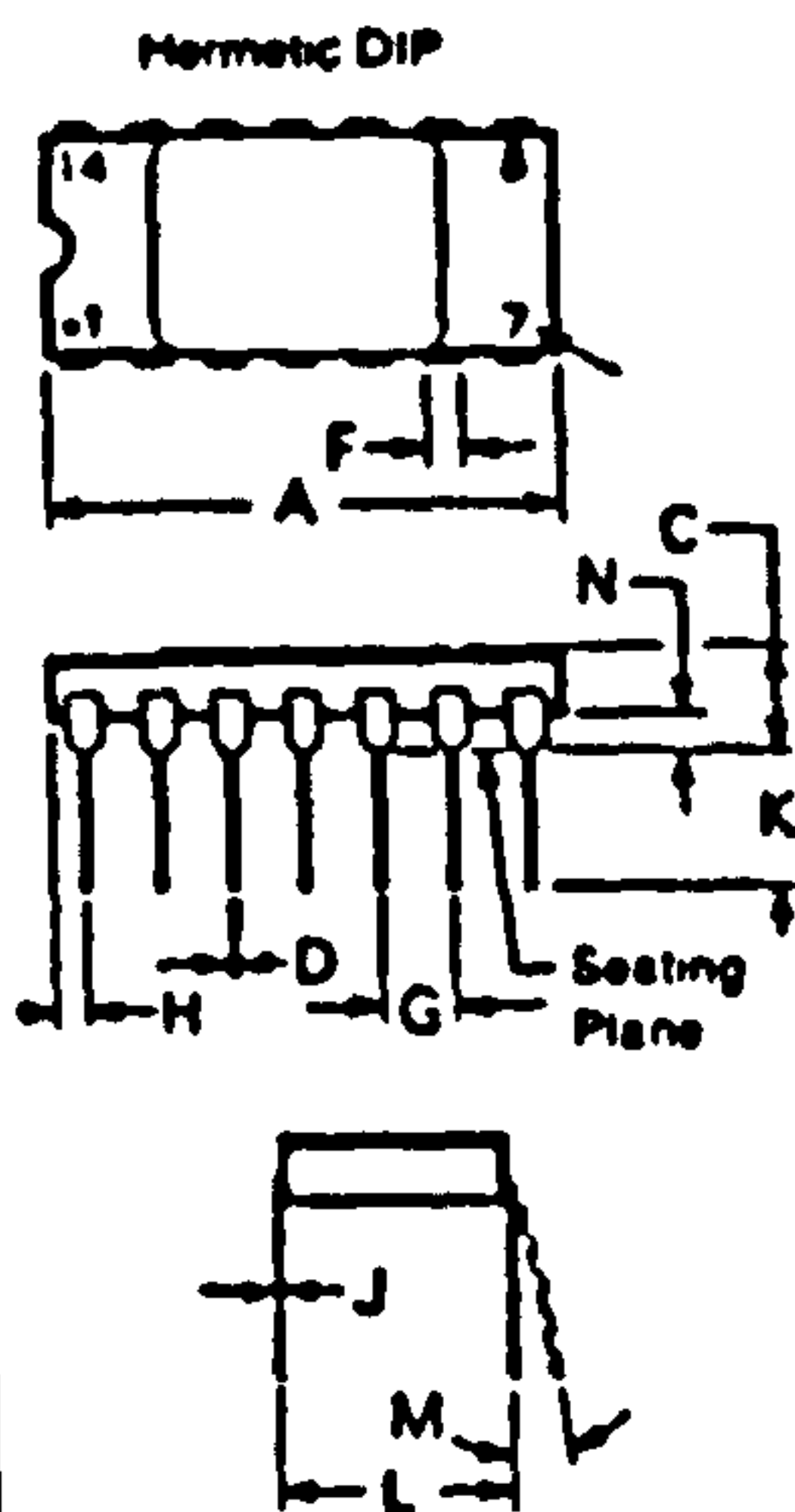


Case - $-V_{cc}$
 Leads in true position within $0.010"$ (0.25mm) R at MMC at seating plane
 Pin numbers shown for reference only
 Numbers may not be marked on package

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.35	0.70	8.91	17.78
B	0.305	0.375	7.75	9.53
C	0.185	0.195	4.70	4.93
D	0.18	0.21	4.57	5.33
E	0.10	0.10	2.54	2.54
F	0.10	0.10	2.54	2.54
G	220 BASIC		5.64 BASIC	
H	0.70	0.74	17.78	18.80
J	0.70	0.85	17.78	21.59
K	0.00	-	0.00	0.00
L	1.20	1.60	30.48	40.64
M	26° BASIC		26° BASIC	
N	1.10	1.20	27.94	30.48

BOTTOM VIEW

G Package



Leads in true position within $0.010"$ (0.25mm) R at MMC at seating plane
 Pin numbers shown for reference only
 Numbers may not be marked on package

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.70	1.10	17.82	28.03
C	0.05	0.10	1.27	2.54
D	0.15	0.21	3.81	5.33
F	0.45	0.60	11.43	15.24
G	100 BASIC		2.54 BASIC	
H	0.25	0.70	6.35	17.78
J	0.08	0.12	2.03	3.05
K	1.20	2.40	30.48	61.00
L	300 BASIC		7.62 BASIC	
M	-	15°	-	15°
N	0.05	0.10	1.27	2.54

ORDERING INFORMATION

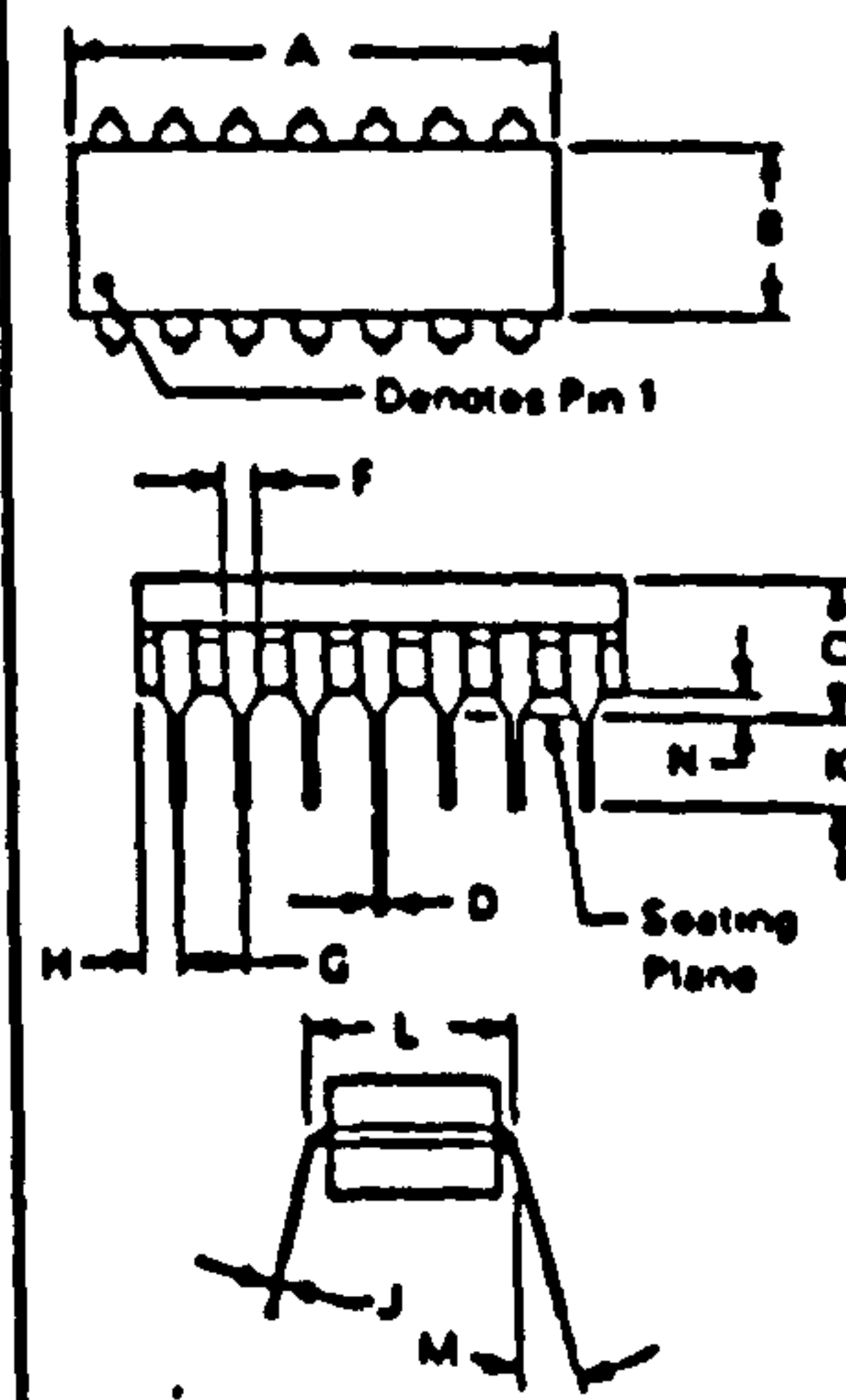
Basic Model Number INA101 C G

Performance Grade Code
 S: -55°C to $+125^{\circ}\text{C}$
 A, C: -25°C to $+85^{\circ}\text{C}$
 H: 0°C to $+70^{\circ}\text{C}$

Package Code
 M: TO-100
 G: 14-Pin Hermetic DIP
 P: 14-Pin Plastic DIP

TO-100 (M Suffix)	Hermetic DIP (G Suffix)	Plastic DIP (P Suffix)
INA101AM	INA101AG	INA101HP
INA101CM	INA101CG	
INA101SM	INA101SG	

P Package



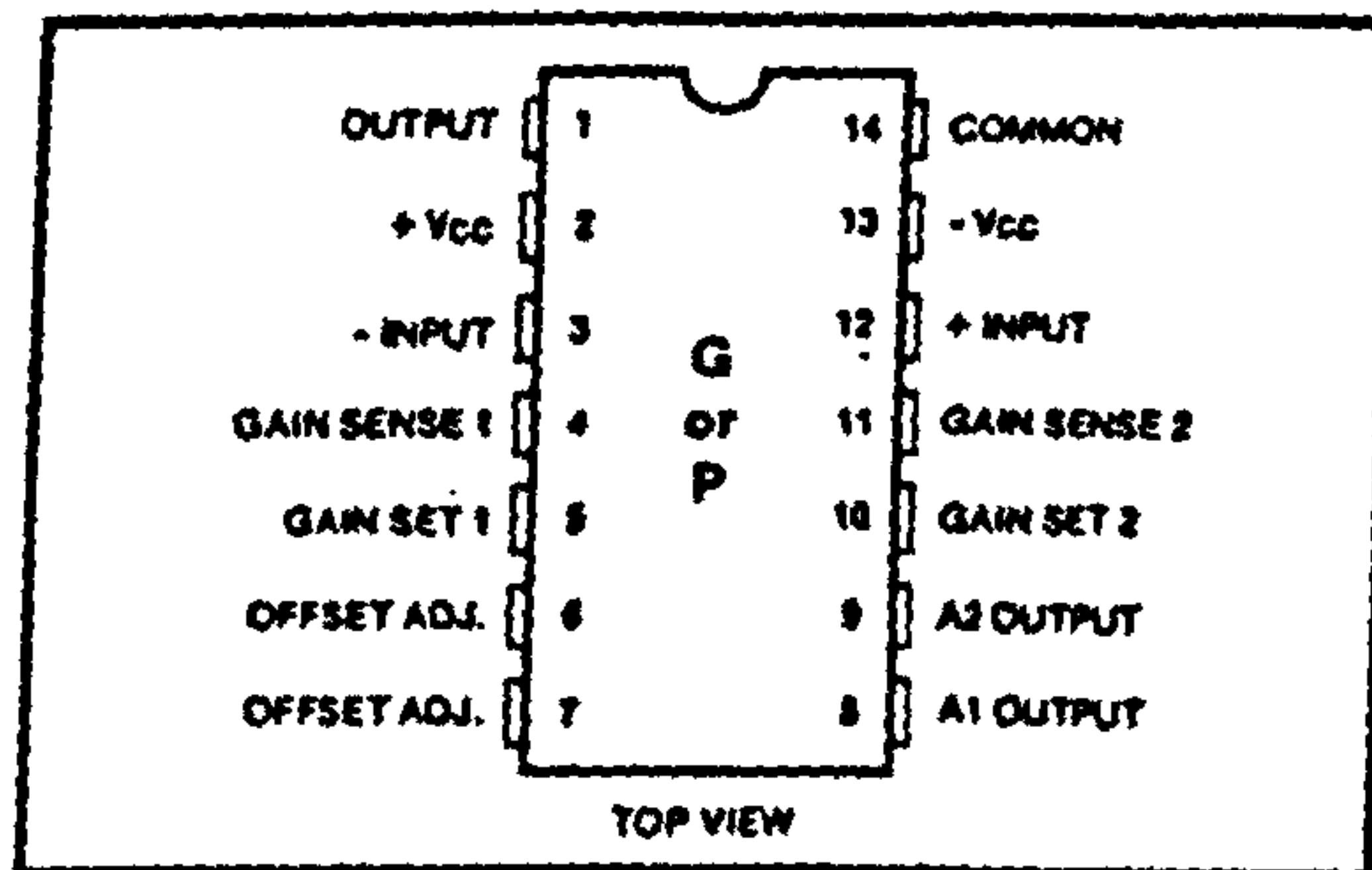
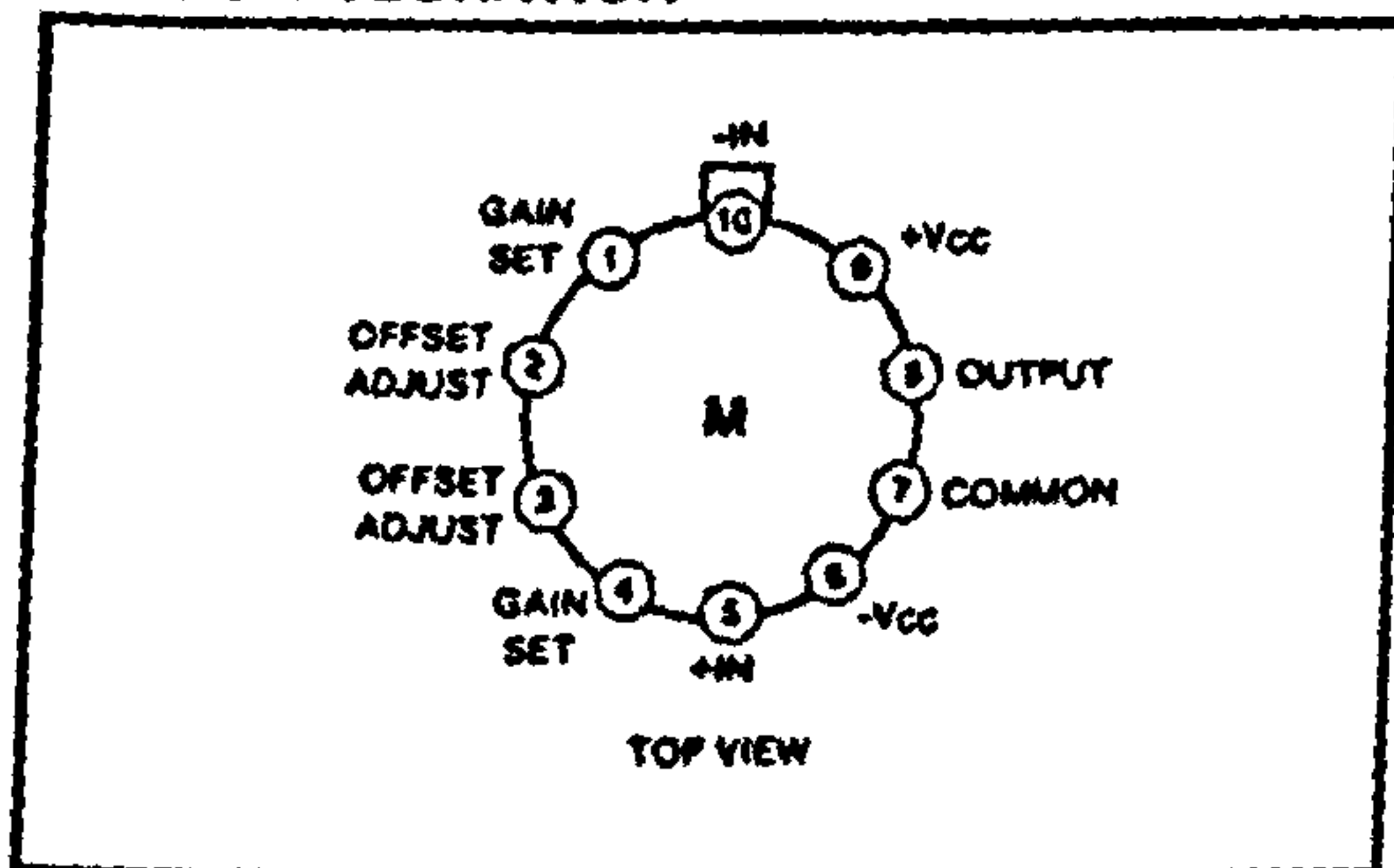
Case - $-V_{cc}$
 Leads in true position within $0.10"$ (2.5mm) R at MMC at seating plane
 Pin numbers shown for reference only
 Numbers may not be marked on package

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.60	1.05	15.24	26.67
B	0.220	0.200	5.59	5.08
C	-	0.200	-	5.08
D	0.18	0.23	4.57	5.84
F	0.30	0.70	7.62	17.78
G	100 BASIC		2.54 BASIC	
H	0.20	0.95	5.08	24.13
J	0.08	0.15	2.03	3.81
K	1.00	-	25.40	-
L	300 BASIC		7.62 BASIC	
M	-	15°	-	15°
N	0.20	0.60	5.08	15.24

ABSOLUTE MAXIMUM RATINGS

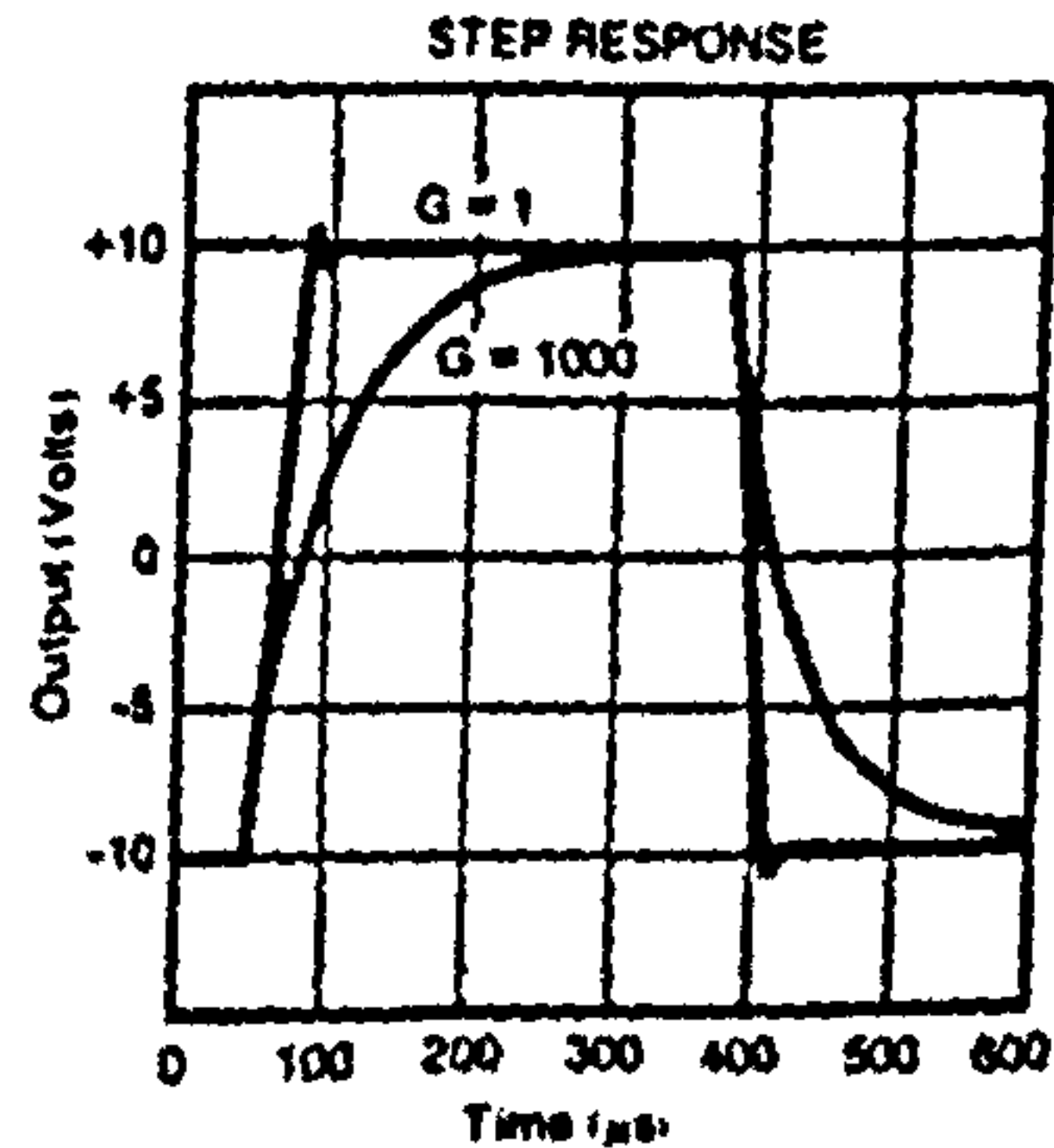
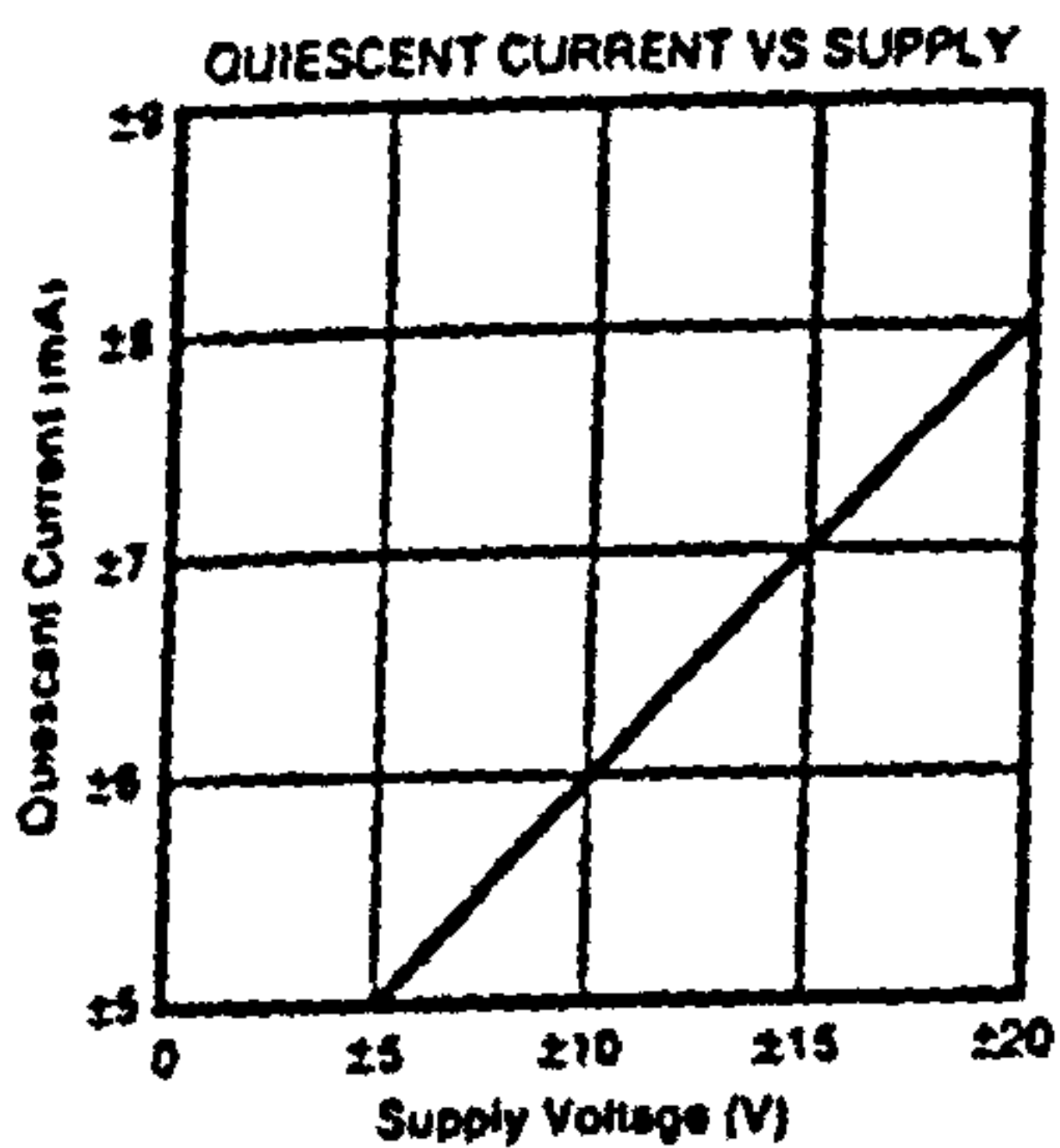
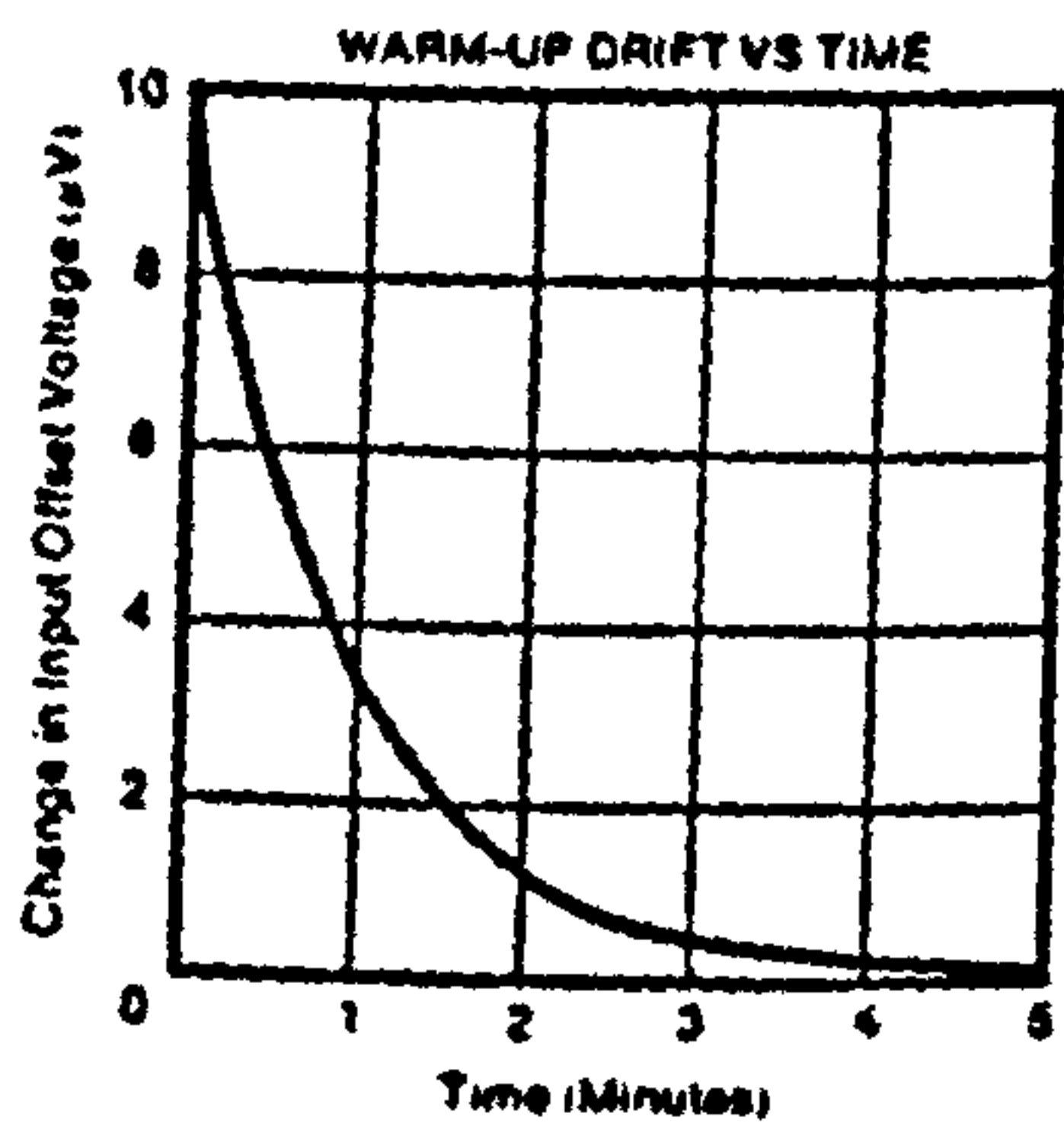
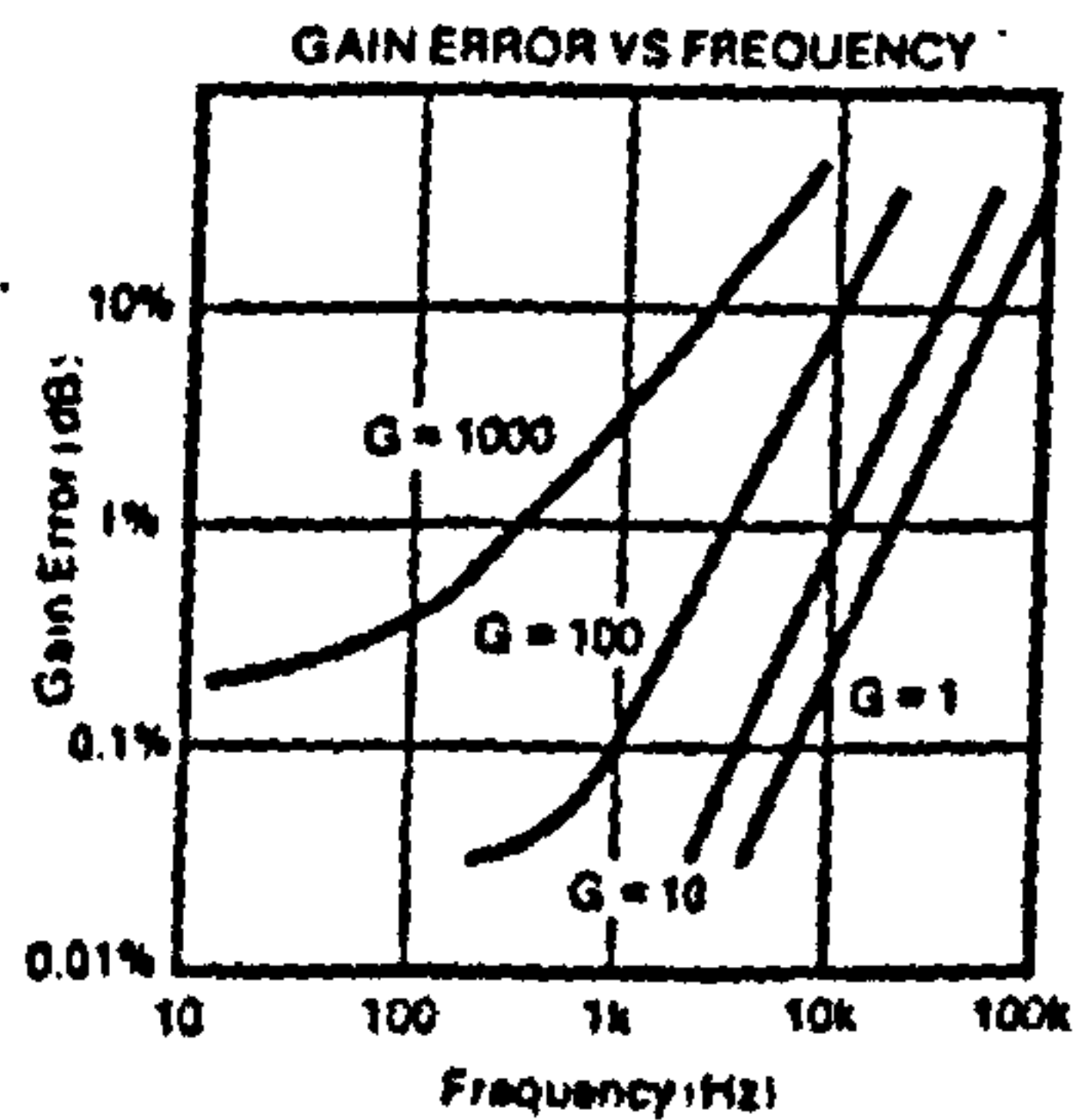
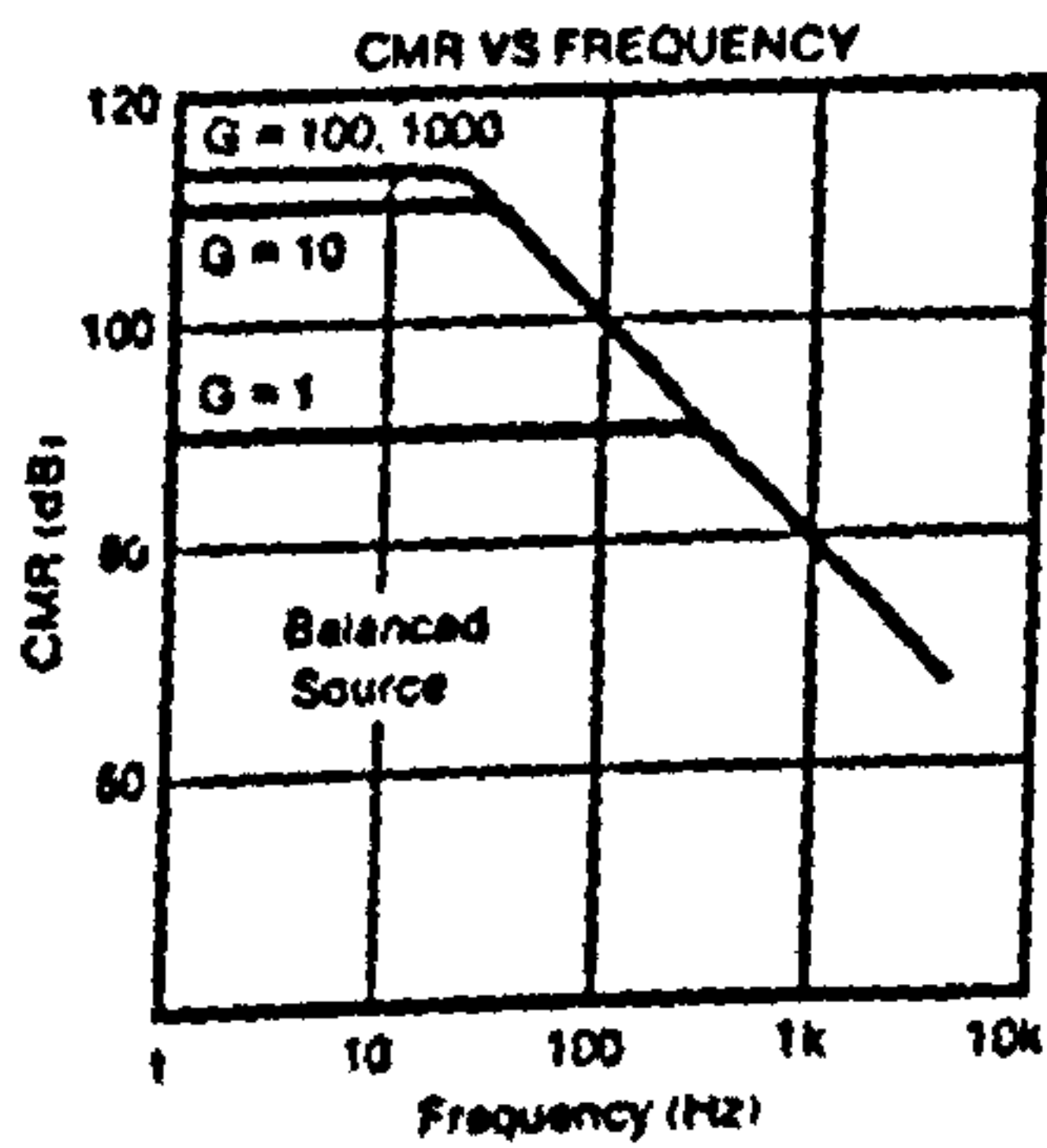
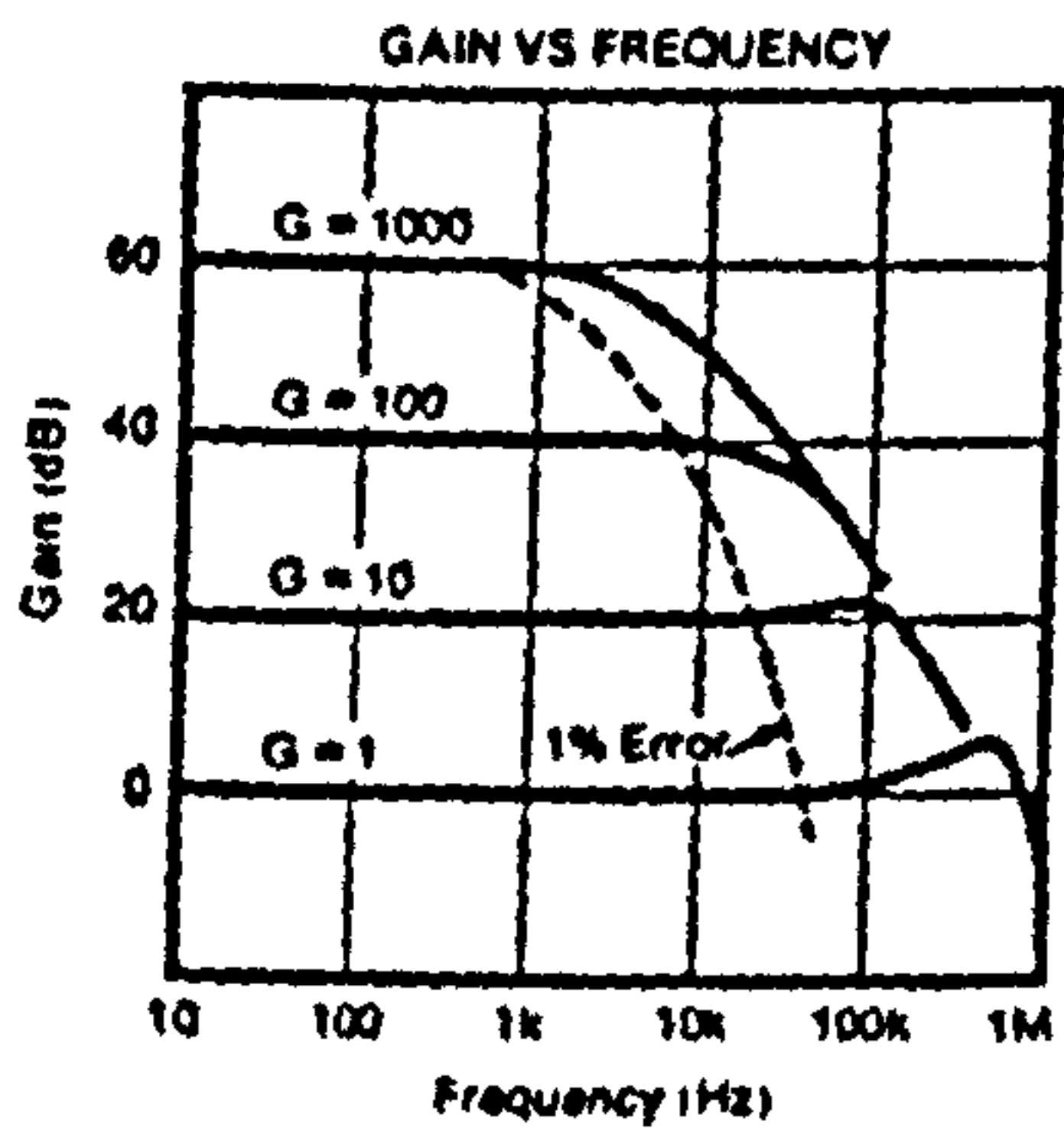
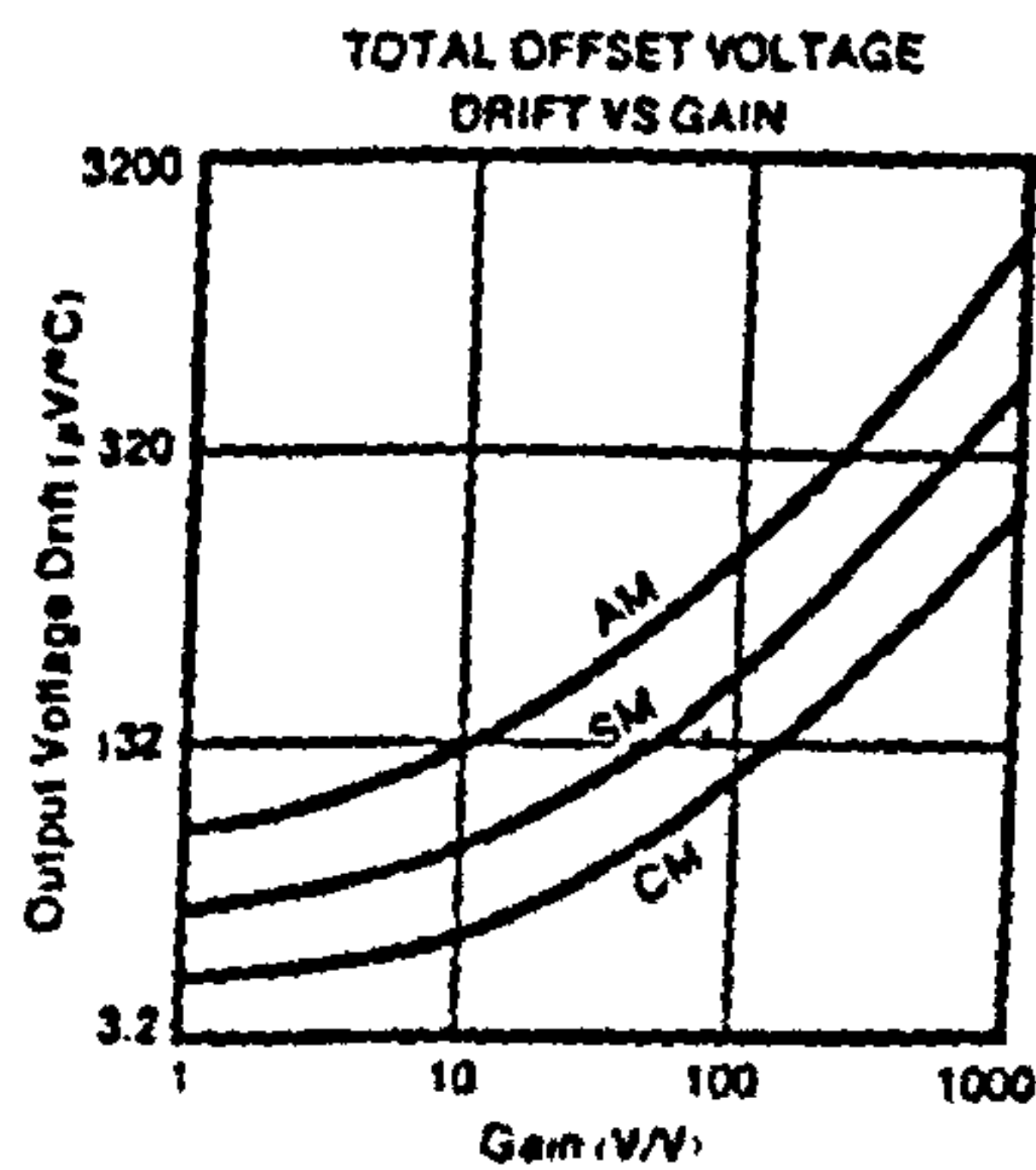
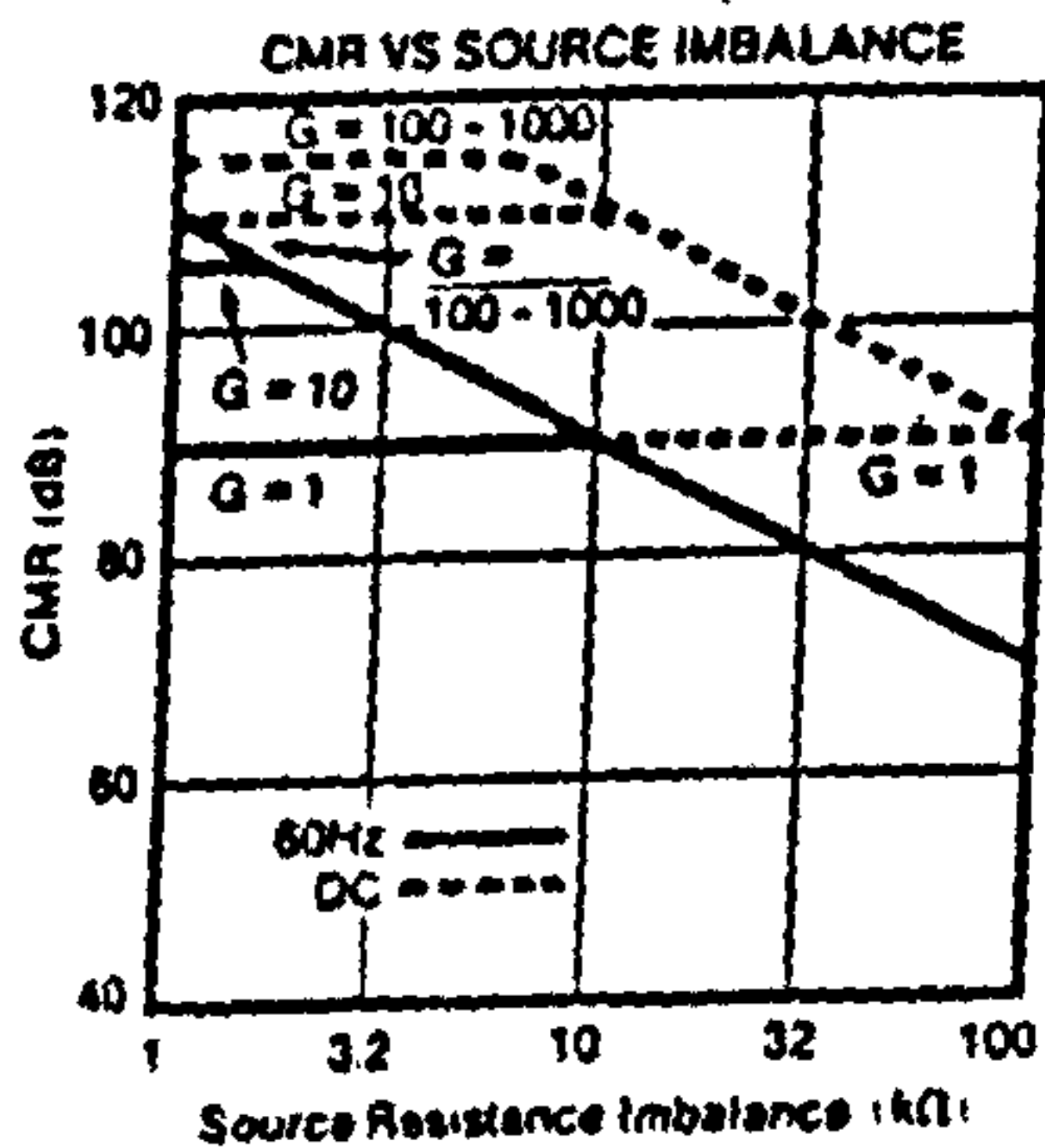
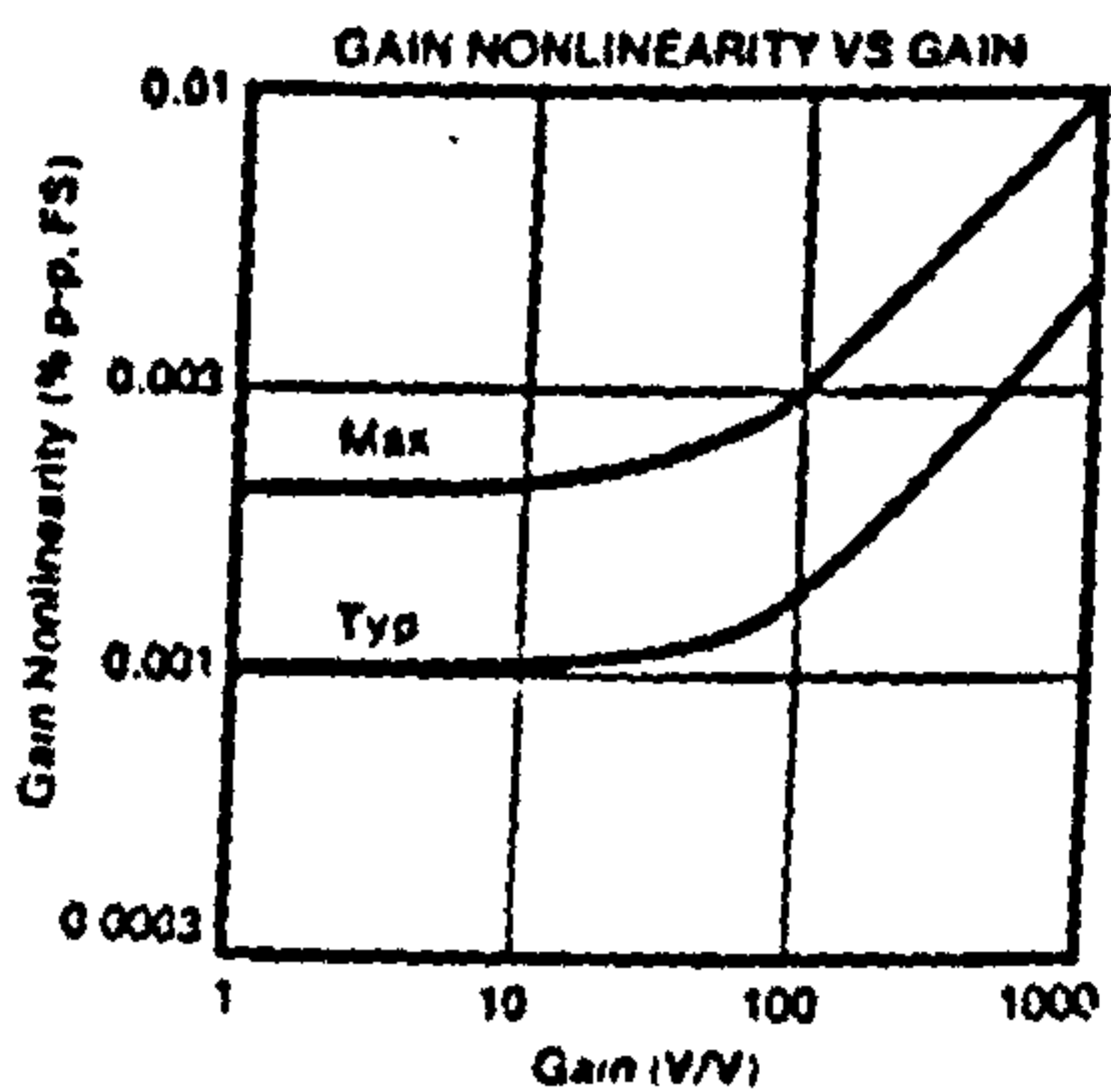
Supply	$\pm 20\text{V}$
Internal Power Dissipation	600mW
Input Voltage Range	$\pm V_{cc}$
Operating Temperature Range	-55°C to $+125^{\circ}\text{C}$
Storage Temperature Range:	
M, G	-65°C to $+150^{\circ}\text{C}$
P	-40°C to $+85^{\circ}\text{C}$
Lead Temperature (soldering 10 seconds)	$+300^{\circ}\text{C}$
Output Short-Circuit Duration	Continuous to ground

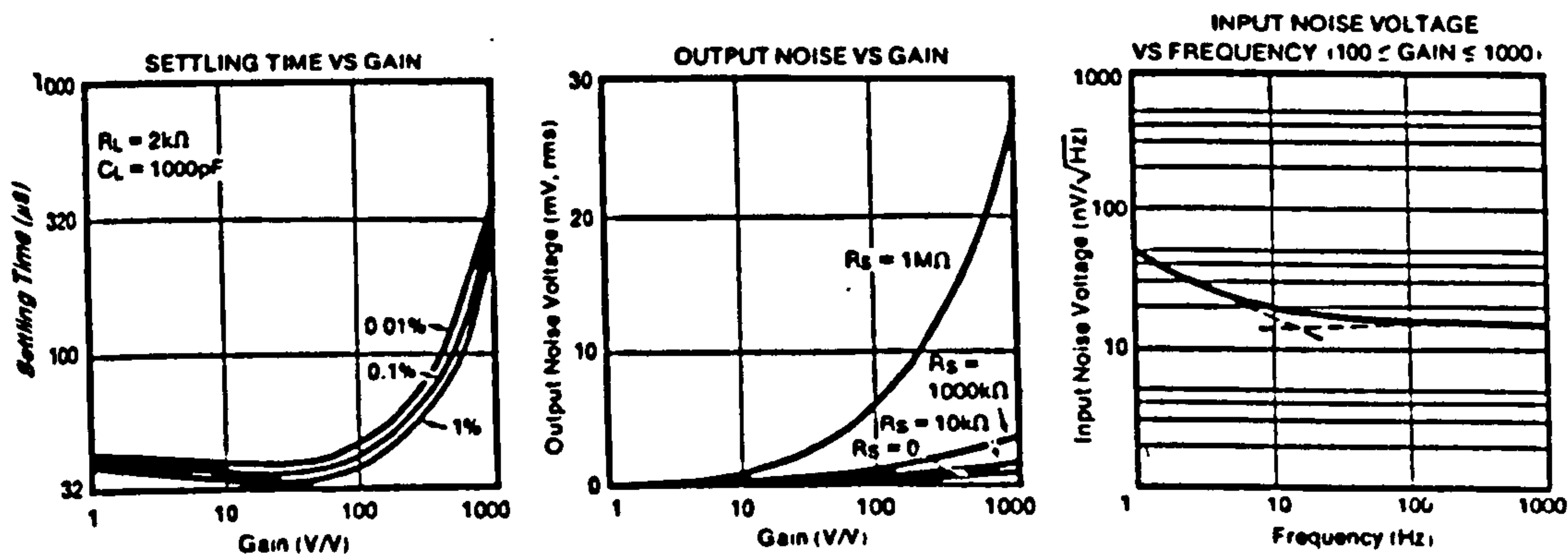
PIN CONFIGURATION



TYPICAL PERFORMANCE CURVES

At +25°C and in circuit of Figure 2 unless otherwise noted.





DISCUSSION OF PERFORMANCE

INSTRUMENTATION AMPLIFIERS

Instrumentation amplifiers are differential input closed-loop gain blocks whose committed circuit accurately amplifies the voltage applied to their inputs. They respond only to the difference between the two input signals and exhibit extremely-high input impedance, both differentially and common-mode. Feedback networks are packaged within the amplifier module. Only one external gain setting resistor must be added. An operational amplifier, on the other hand, is an open-loop, uncommitted device that requires external networks to close the loop. While op amps can be used to achieve the same basic function as instrumentation amplifiers, it is very difficult to reach the same level of performance. Using op amps often leads to design trade-offs when it is necessary to amplify low level signals in the presence of common-mode voltages while maintaining high input impedances. Figure 1 shows a simplified model of an instrumentation amplifier that eliminates most of the problems.

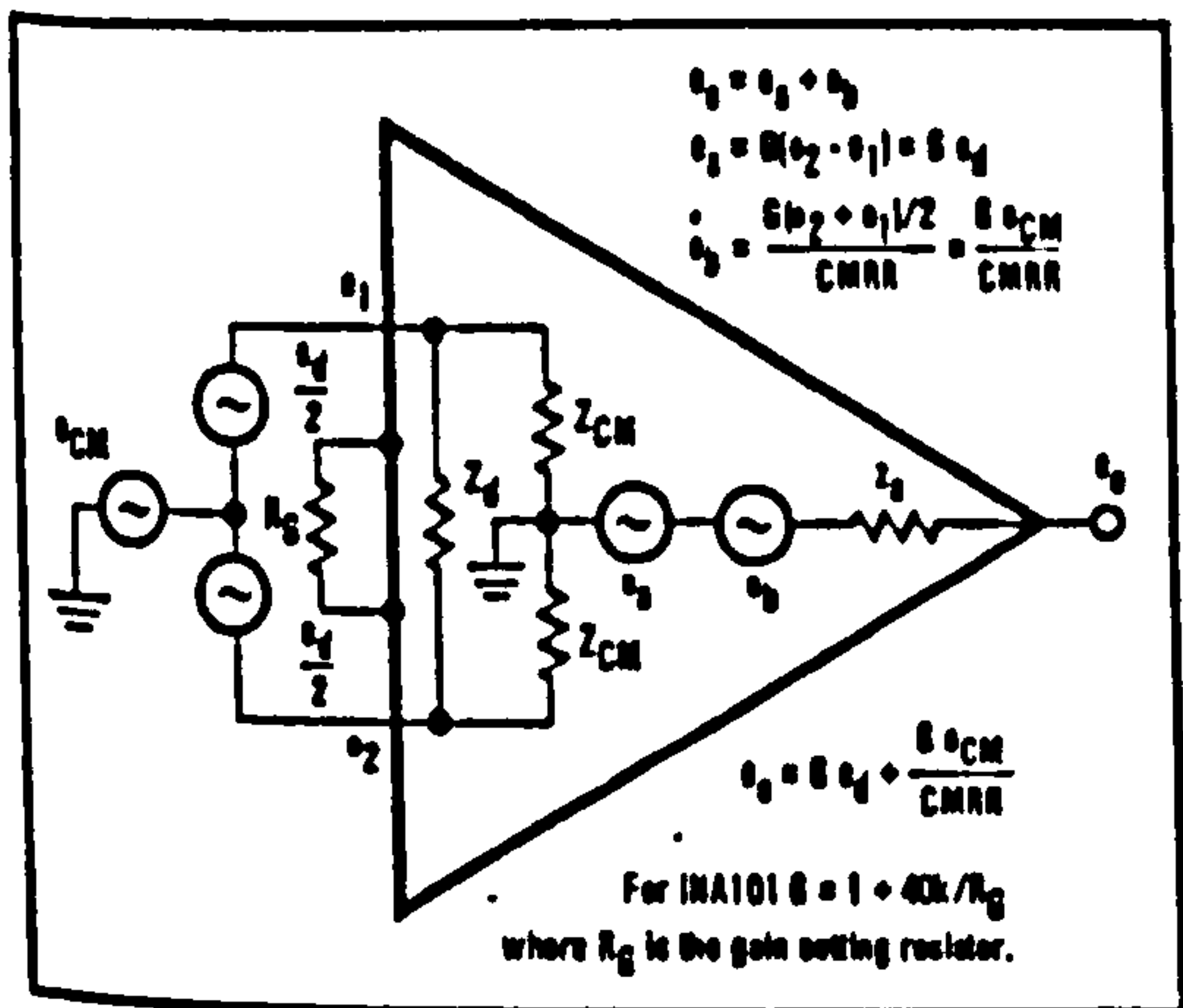


FIGURE 1. Model of an Instrumentation Amplifier.

THE INA101

Simplified schematics of the INA101 are shown on the first page. It is a three-amplifier device which provides all

the desirable characteristics of a premium performance instrumentation amplifier. In addition, it has features not normally found in integrated circuit instrumentation amplifiers.

The input section (A1 and A2) incorporates high performance, low drift amplifier circuitry. The amplifiers are connected in the noninverting configuration to provide the high input impedance ($10^{10}\Omega$) desirable in the instrumentation amplifier function. The offset voltage and offset voltage versus temperature is low due to the monolithic design and improved even further by the state-of-the-art laser-trimming techniques.

The output section (A3) is connected in a unity-gain difference amplifier configuration. A critical part of this stage is the matching of the four $10k\Omega$ resistors which provide the difference function. These resistors must be initially well matched and the matching must be maintained over temperature and time in order to retain excellent common-mode rejection. (The 106dB minimum at 60Hz for gains greater than $100V/V$ is a significant improvement compared to most other integrated circuit instrumentation amplifiers.)

All of the internal resistors are compatible thin-film nichrome formed with the integrated circuit. The critical resistors are laser-trimmed to provide the desired high gain accuracy and common-mode rejection. Nichrome ensures long-term stability of trimmed resistors and simultaneous achievement of excellent TCR and TCR tracking. This provides gain accuracy and common-mode rejection when the INA101 is operated over wide temperature ranges.

USING THE INA101

Figure 2 shows the simplest configuration of the INA101. The gain is set by the external resistor, R_G with a gain equation of $G = 1 + (40k/R_G)$. The reference and TCR of R_G contribute directly to the gain accuracy and drift.

For gains greater than unity, resistor R_G is connected externally between pins 1 and 4. At high gains where the value of R_G becomes small, additional resistance (i.e., relays, sockets) in the R_G circuit will contribute to a gain error. Care should be taken to minimize this effect.

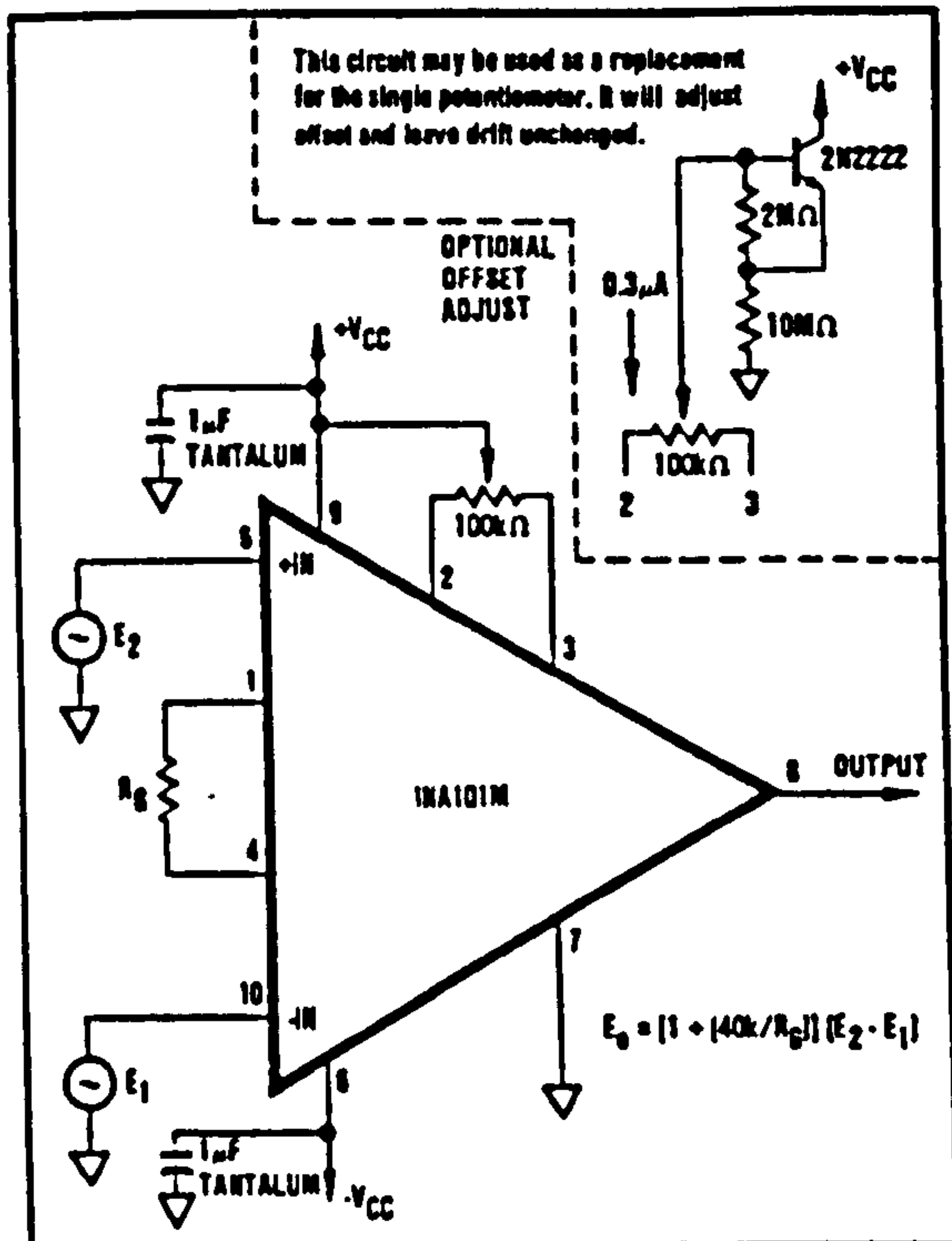


FIGURE 2. Basic Circuit Connection for the INA101 Including Optional Input Offset Null Potentiometer.

The optional offset null capability is shown in Figure 2. The adjustment affects only the input stage component of the offset voltage. Thus, the null condition will be disturbed when the gain is changed. Also, the input drift will be affected by approximately $0.31 \mu\text{V}/^\circ\text{C}$ per $100 \mu\text{V}$ of input offset voltage that is trimmed. Therefore, care should be taken when considering use of the control for removal of other sources of offset. Output offsetting can be accomplished in Figure 3 by applying a voltage to Common (pin 7) through a buffer amplifier. This limits the resistance in series with pin 7 to minimize CMR error. Resistance above 0.1Ω will cause the common-mode rejection to fall below 106dB. Be certain to keep this resistance low.

It is important to not exceed the input amplifiers' dynamic range. The amplified differential input signal and its associated common-mode voltage should not cause the output of A_1 or A_2 to exceed approximately $\pm 10\text{V}$ or nonlinear operation will result.

BASIC CIRCUIT CONNECTION

The basic circuit connection for the INA101 is shown in Figure 2. The output voltage is a function of the differential input voltage times the gain.

OPTIONAL OFFSET ADJUSTMENT PROCEDURE

It is frequently desirable to null the input component of offset (Figure 2) and occasionally that of the output (Figure 3). The quality of the potentiometer will affect the results, therefore, choose one with good temperature and mechanical-resistance stability. The procedure is as follows:

1. Set $E_1 = E_2 = 0\text{V}$ (be sure a good ground return path exists to the input).
2. Set the gain to the desired value by choosing R_G .
3. Adjust to $100\text{k}\Omega$ potentiometer in Figure 2 until the output reads $0\text{V} \pm 1\text{mV}$ or desired setting. Note that the offset will change when the gain is changed. If the output component of offset is to be removed or if it is desired to establish an intentional offset, adjust the $100\text{k}\Omega$ potentiometer in Figure 3 until the output reads $0\text{V} \pm 1\text{mV}$ or desired setting. Note that the offset will not change with gain, but be sure to use a stable external amplifier with good DC characteristics. The range of adjustment is $\pm 15\text{mV}$ as shown. For larger ranges change the ratio of R_1 to R_2 .

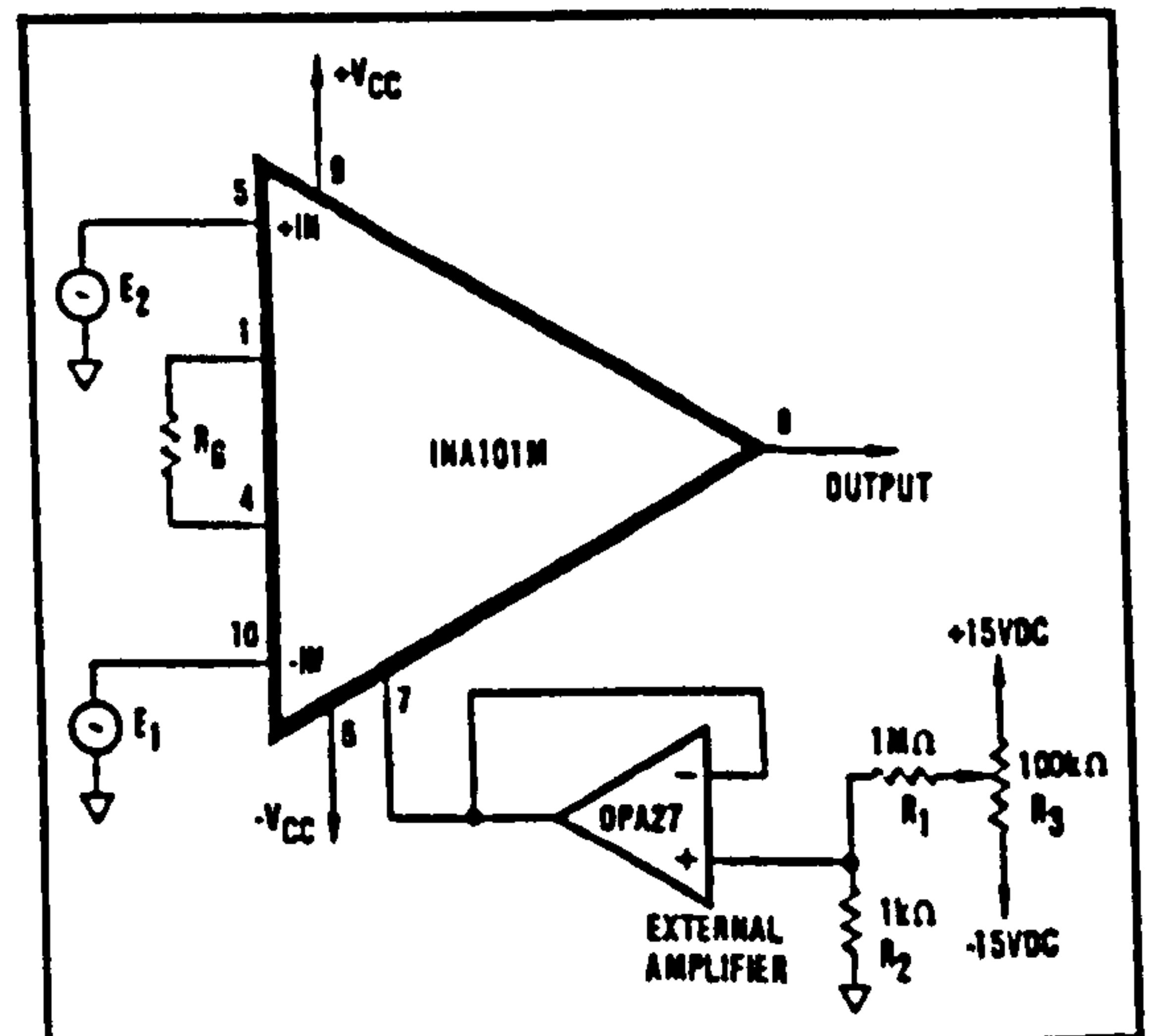


FIGURE 3. Optional Output Offset Nulling or Offsetting Using External Amplifier (Low Impedance to Pin 7).

THERMAL EFFECTS ON OFFSET

To maintain specified offset performance, especially in high gain, prevent air currents from circulating around the input pins. This can be done by using a skirted heat sink on the INA101M package. Rapid changes in die temperature and thermocouple effects on the pins will then be minimized. Surrounding the package with low power components will also help to reduce air flow across the package and pins.

TYPICAL APPLICATIONS

Many applications of instrumentation amplifiers involve the amplification of low level differential signals from

bridges and transducers such as strain gages, thermocouples, and RTD's. Some of the important parameters include common-mode rejection (differential cancellation of common-mode offset and noise, see Figure 1), input impedance, offset voltage and drift, gain accuracy,

linearity, and noise. The INA101 accomplishes all of these with high precision.

Figures 4 through 16 show some typical applications circuits.

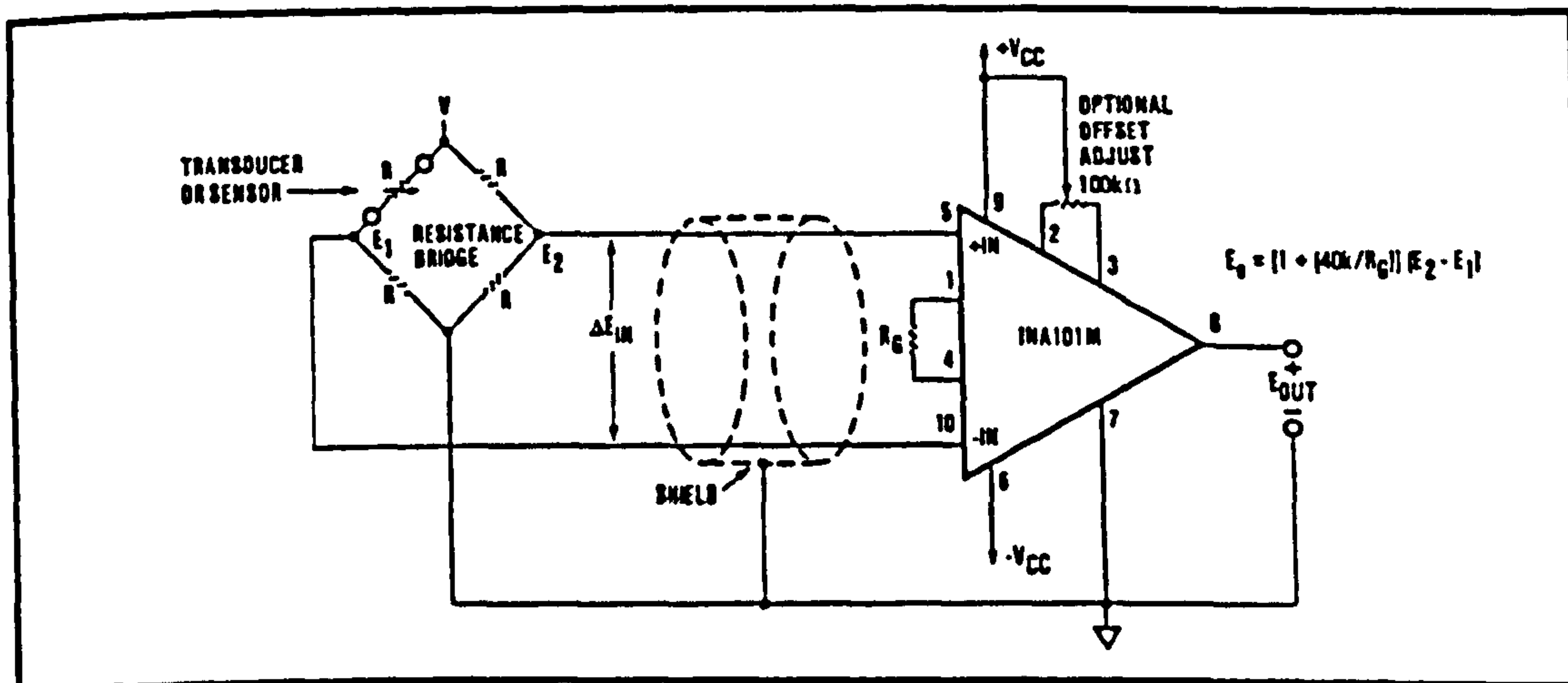


FIGURE 4. Amplification of a Differential Voltage from a Resistance Bridge.

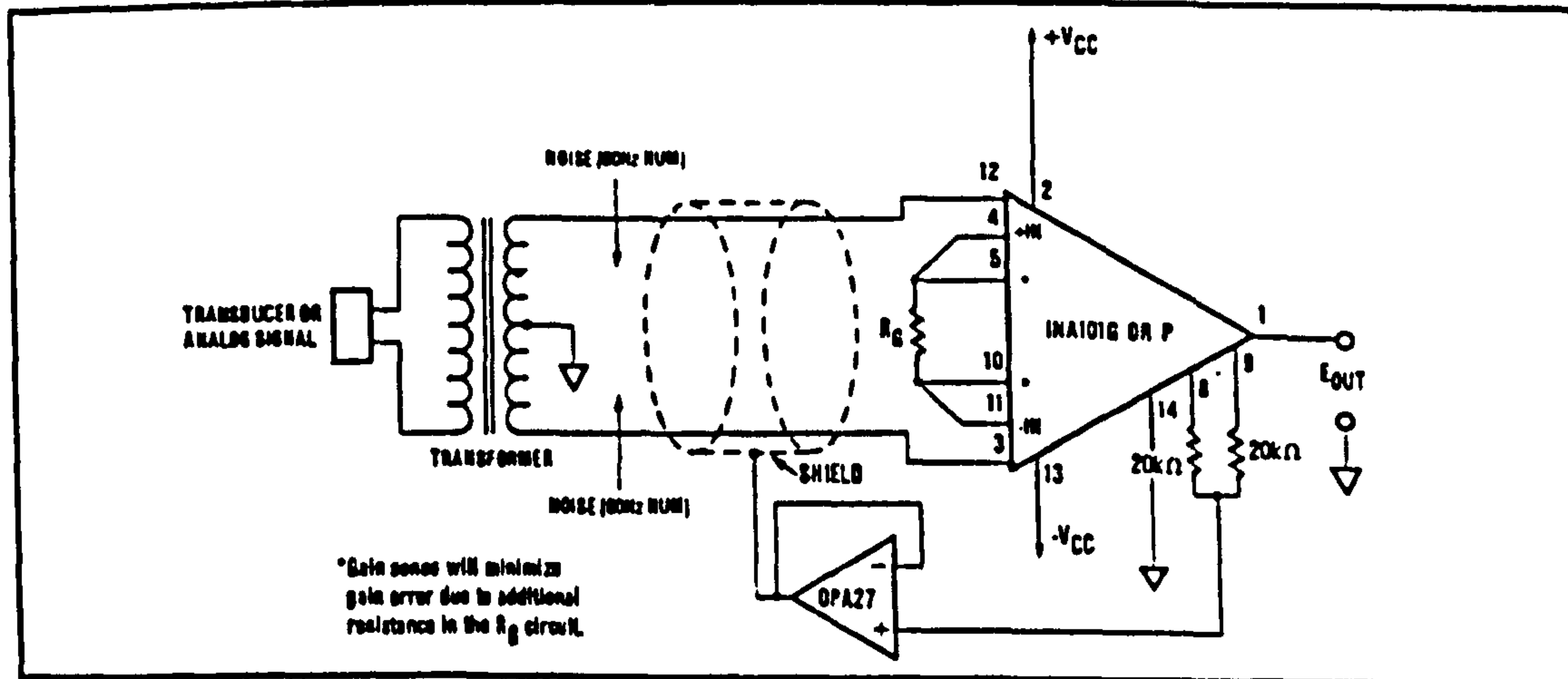


FIGURE 5. Amplification of a Transformer-Coupled Analog Signal.

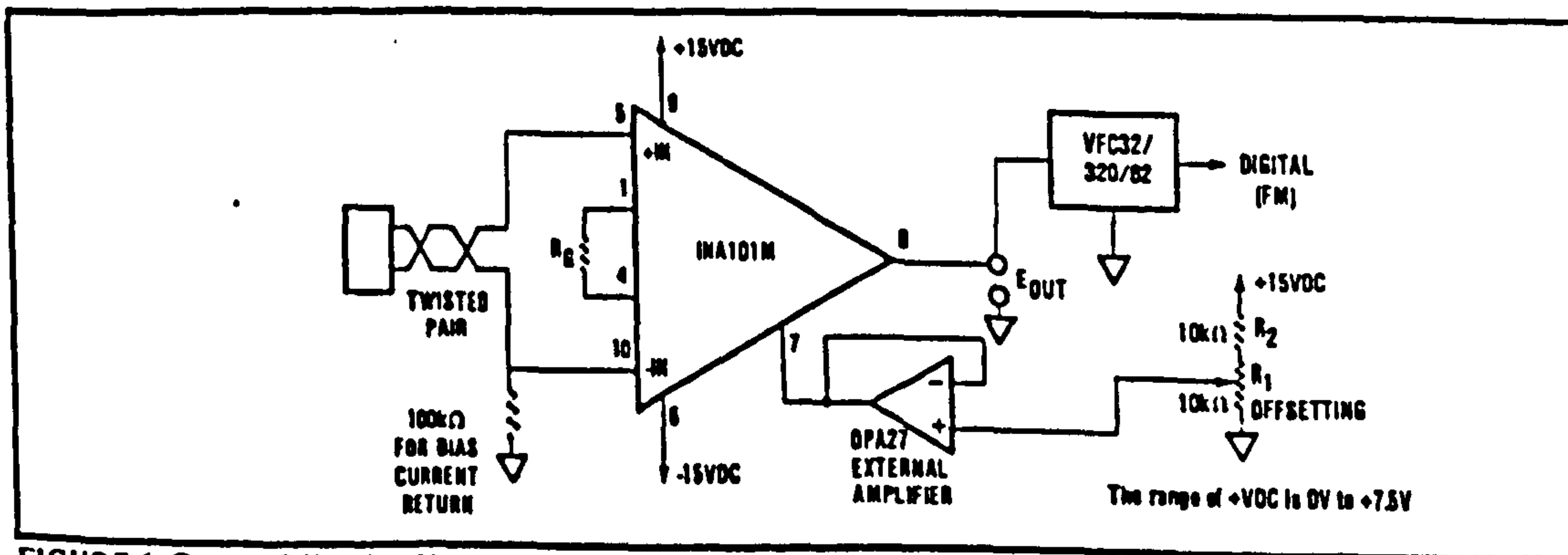


FIGURE 6. Output Offsetting Used to Introduce a DC Voltage for Use with a Voltage-to-Frequency Converter.

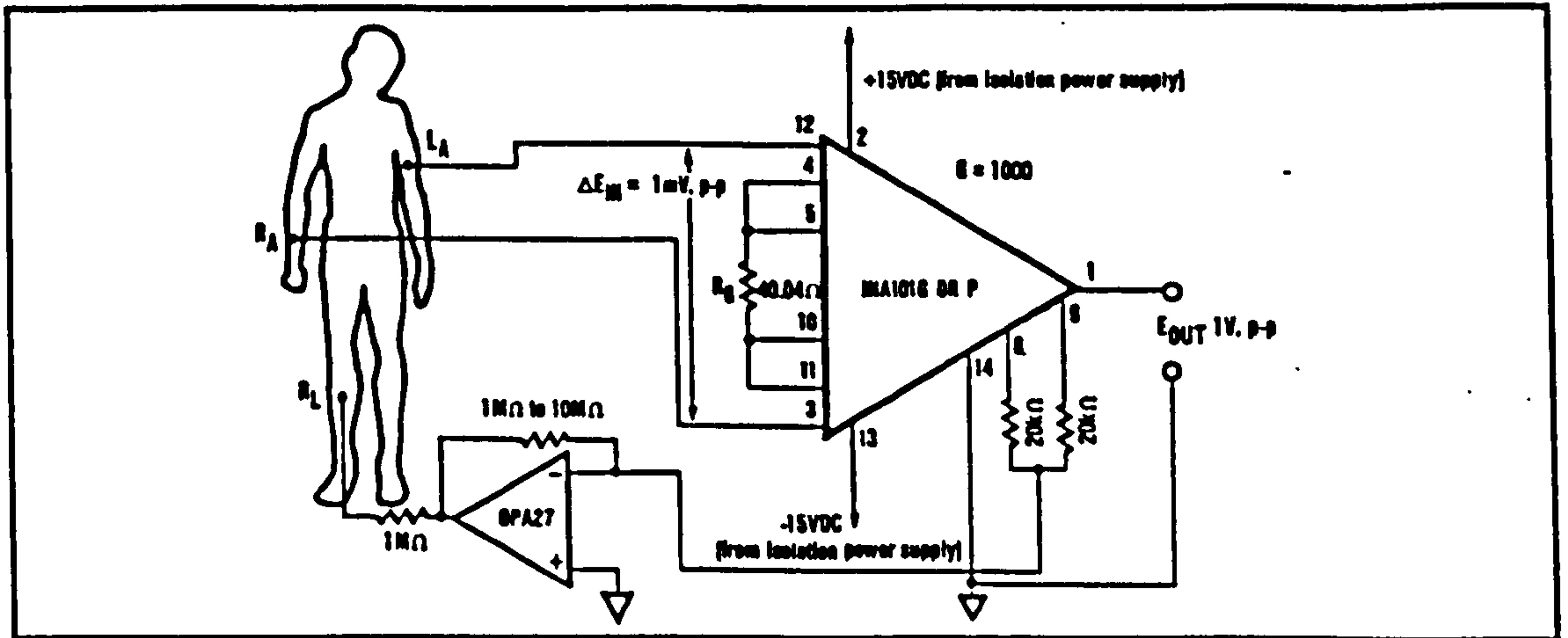


FIGURE 7. ECG Amplifier or Recorder Preamp for Biological Signals.

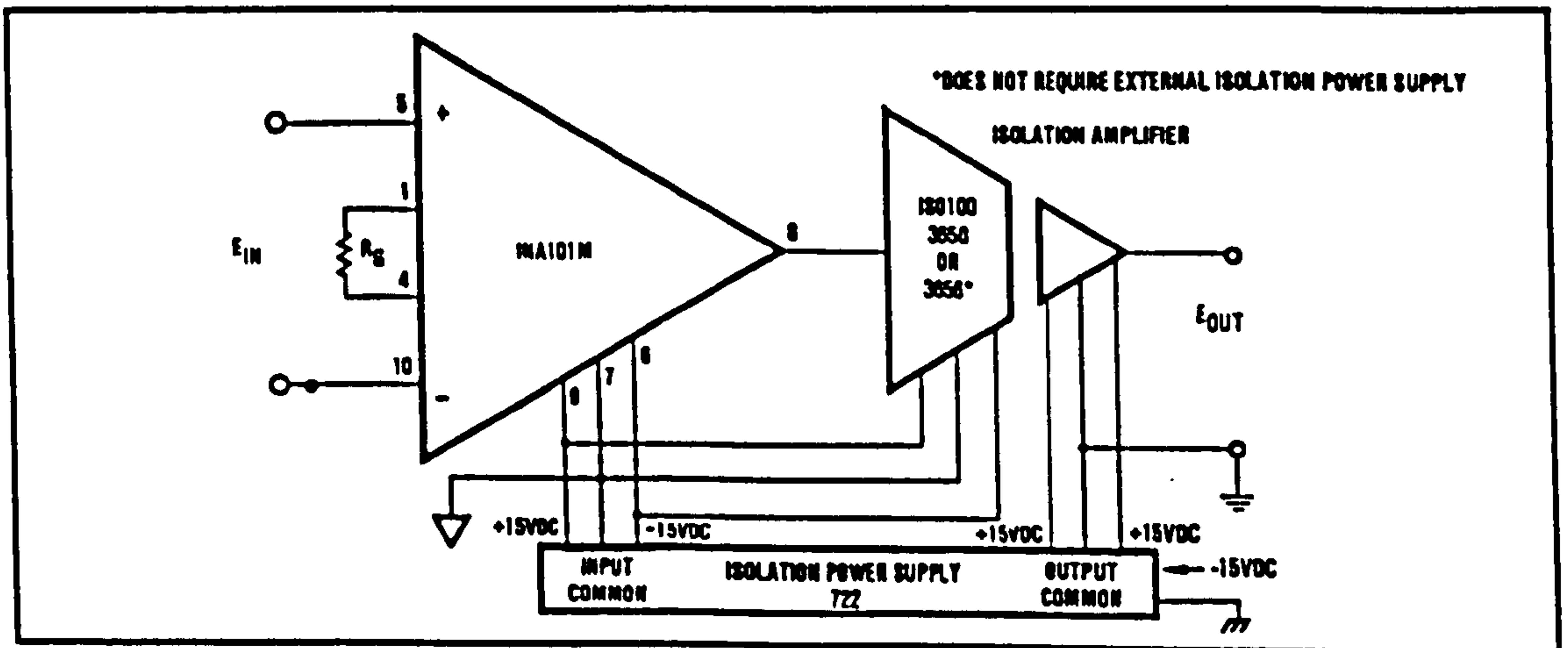


FIGURE 8. Precision Isolated Instrumentation Amplifier.

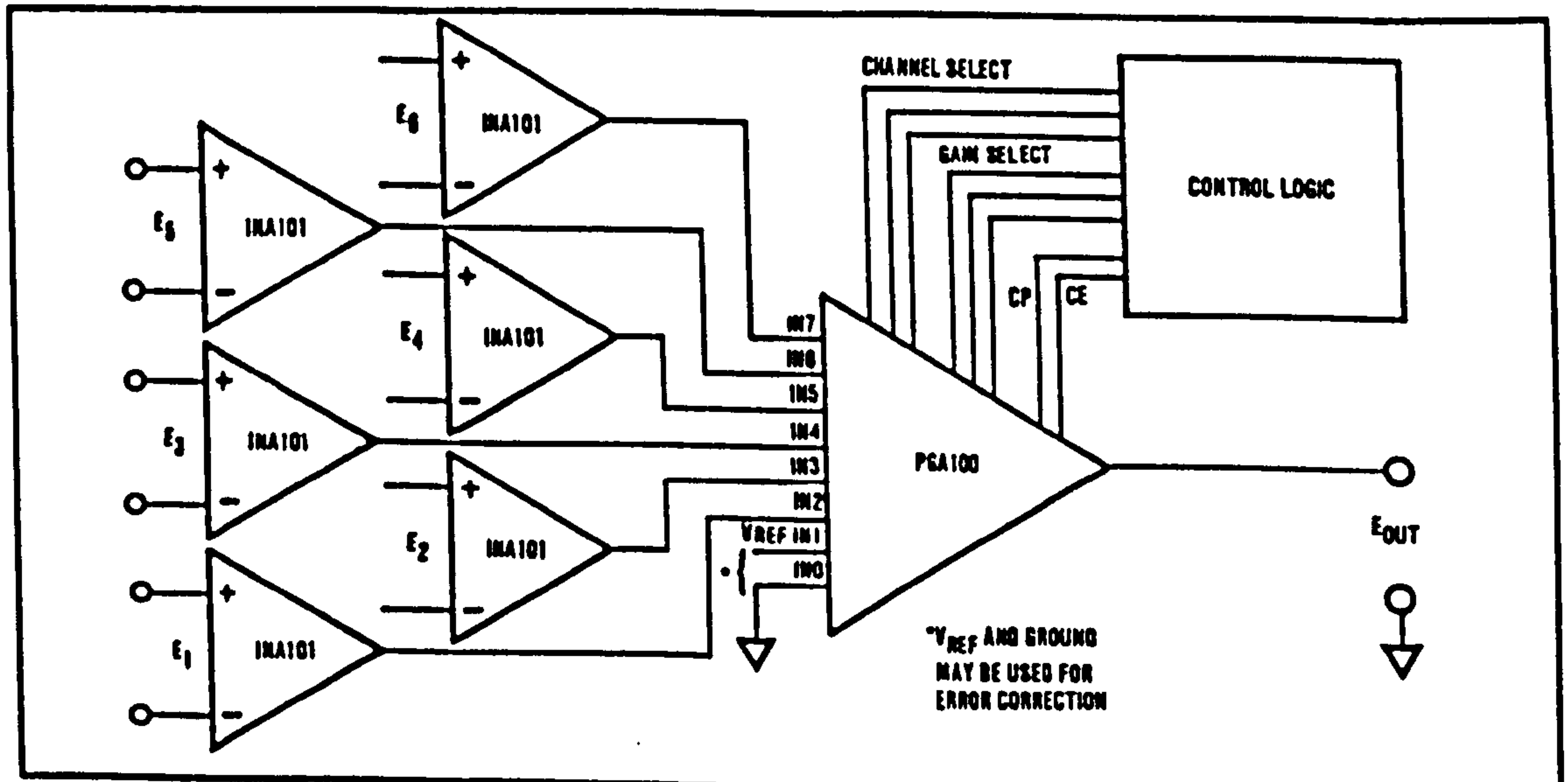


FIGURE 9. Multiple Channel Precision Instrumentation Amplifier.

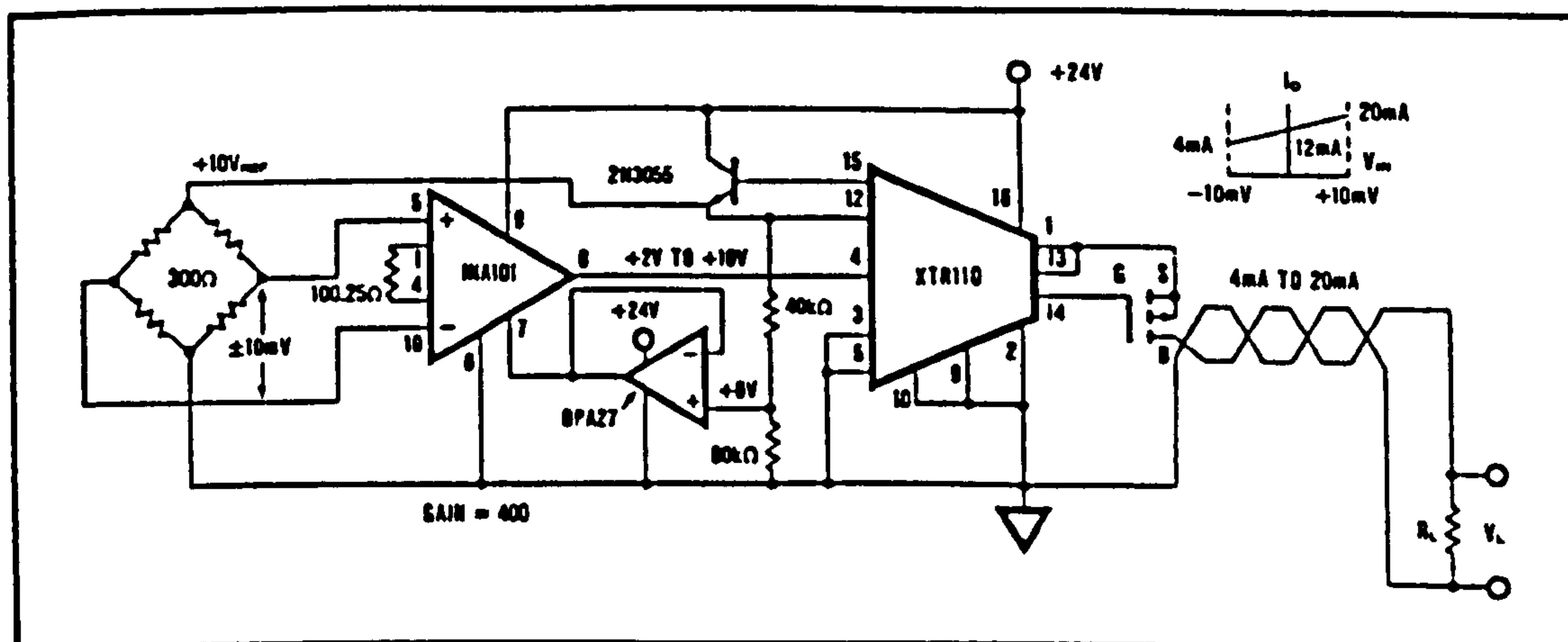


FIGURE 10. 4mA to 20mA Bridge Transmitter Using Single Supply Instrumentation Amplifier.

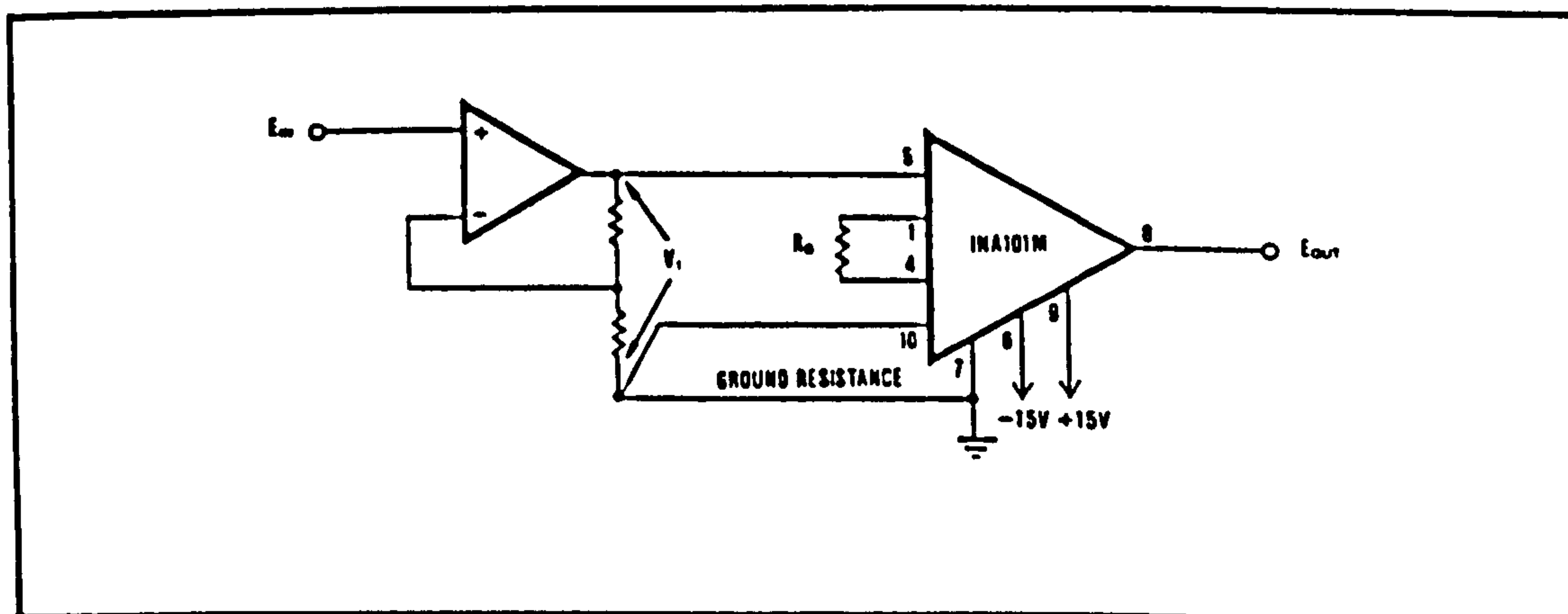


FIGURE 11. Ground Resistance Loop Eliminator (INA101 senses and amplifies V_s accurately).

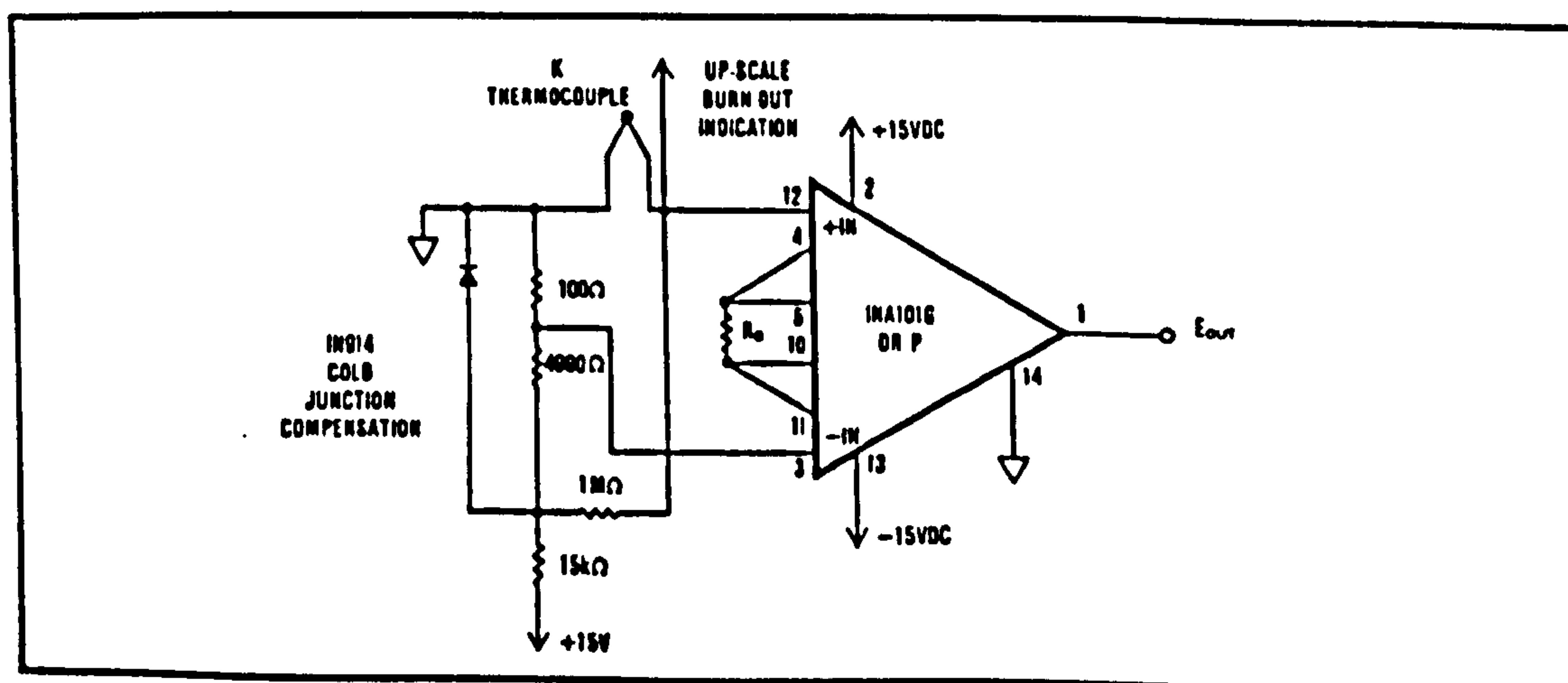


FIGURE 12. Thermocouple Amplifier with Cold Junction Compensation.

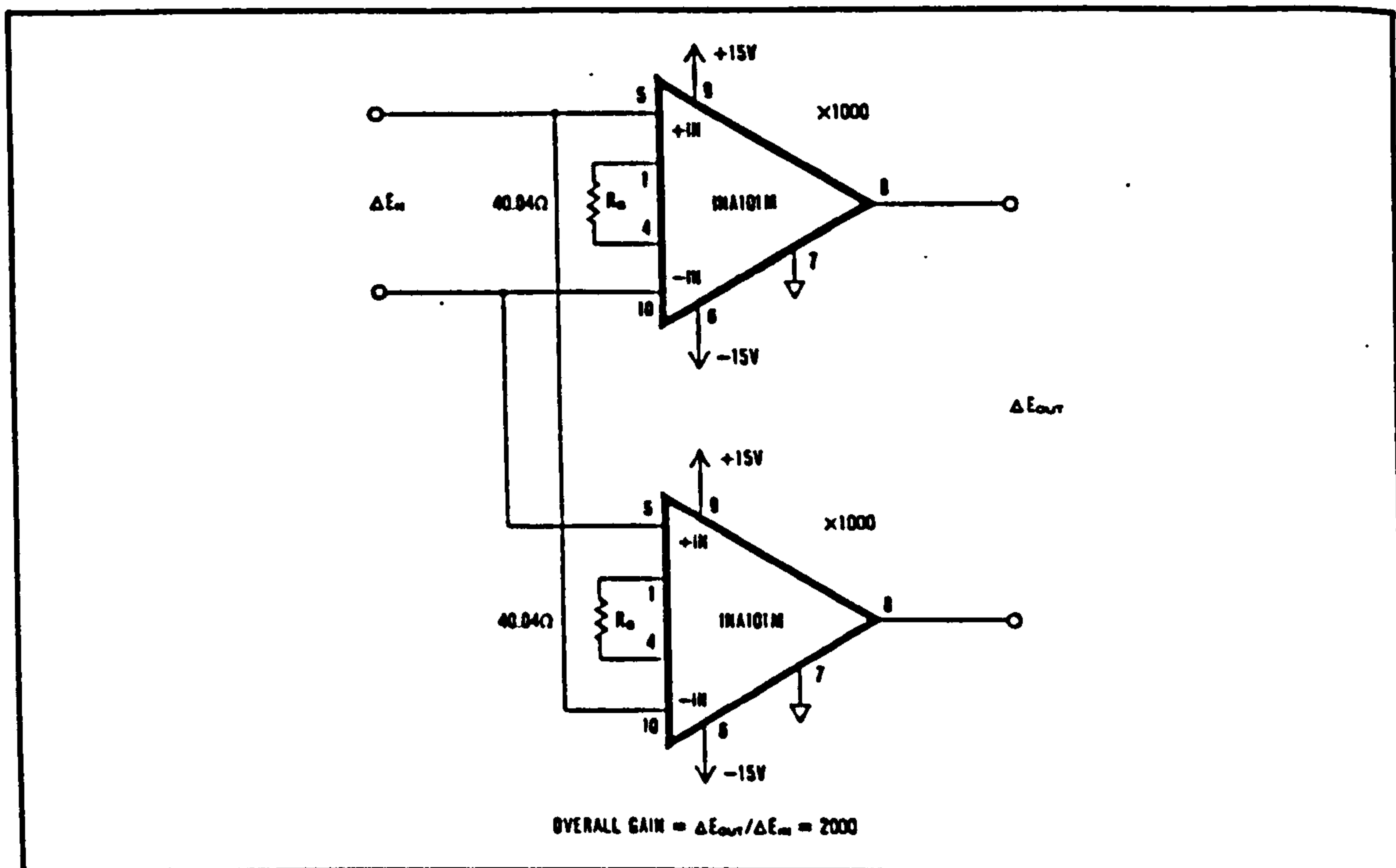


FIGURE 13. Differential Input: Differential Output Amplifier (twice the gain of one INA).

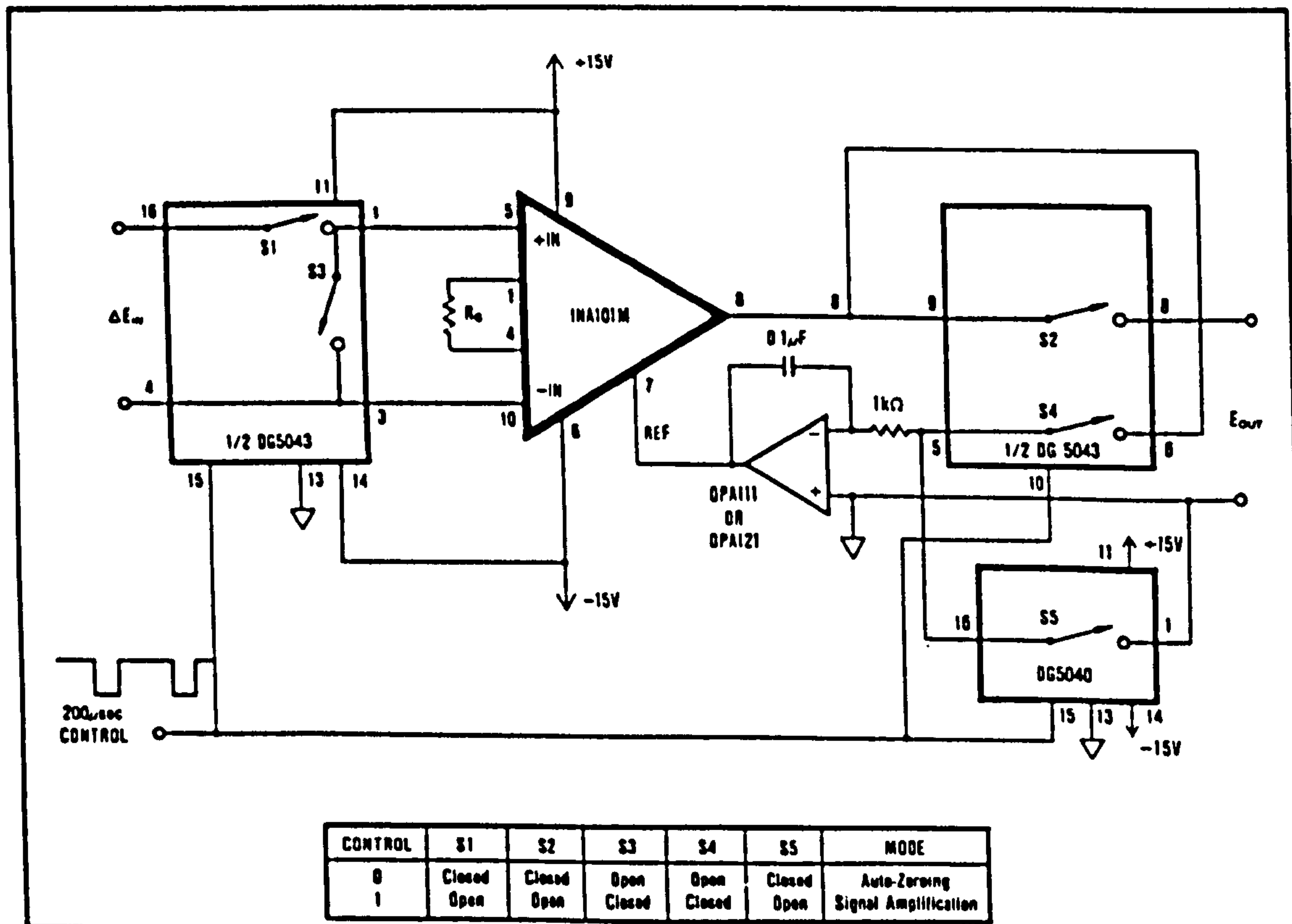


FIGURE 14. Auto-Zeroing Instrumentation Amplifier Circuit.

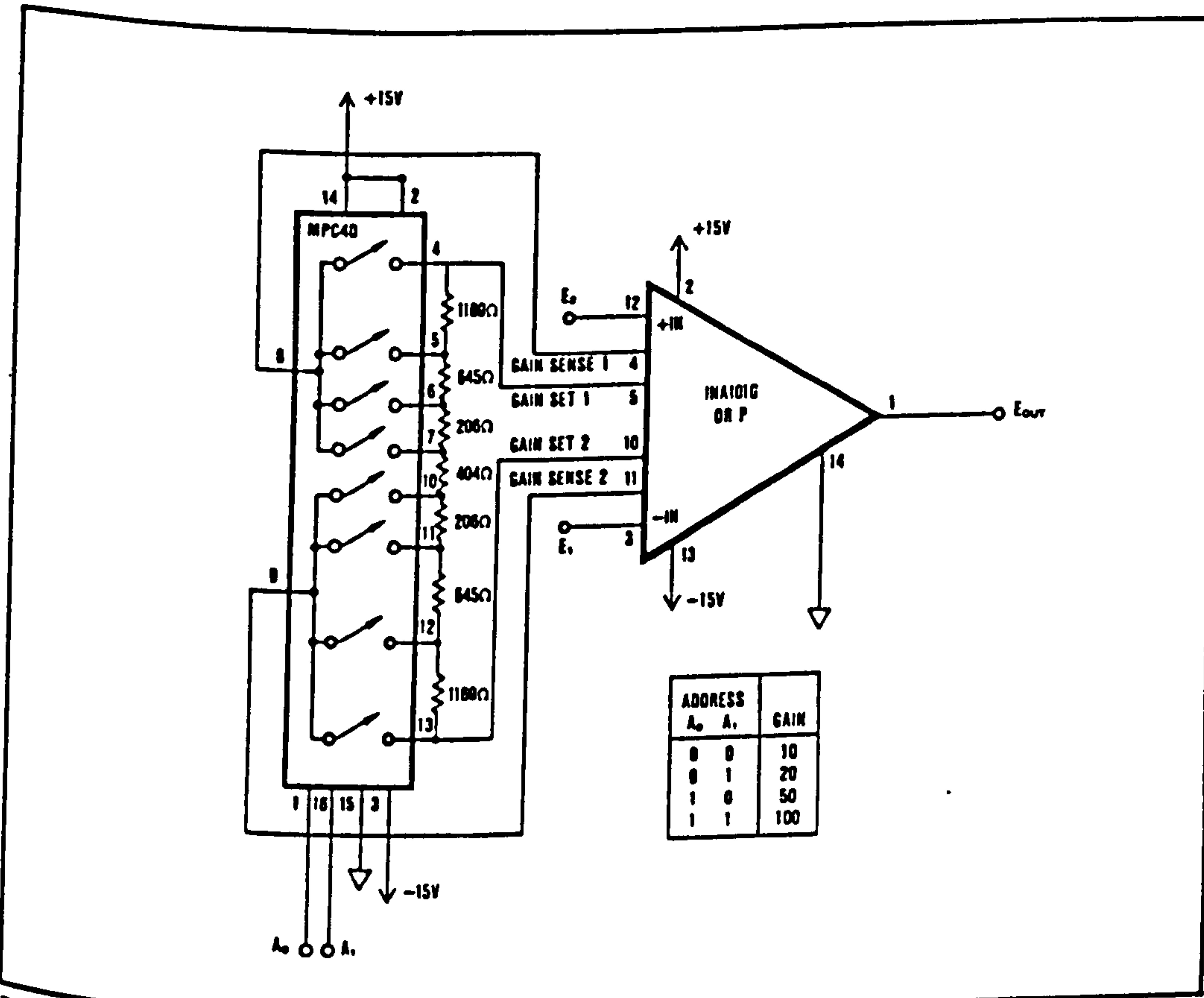


FIGURE 15. Programmable Gain Instrumentation Amplifier.

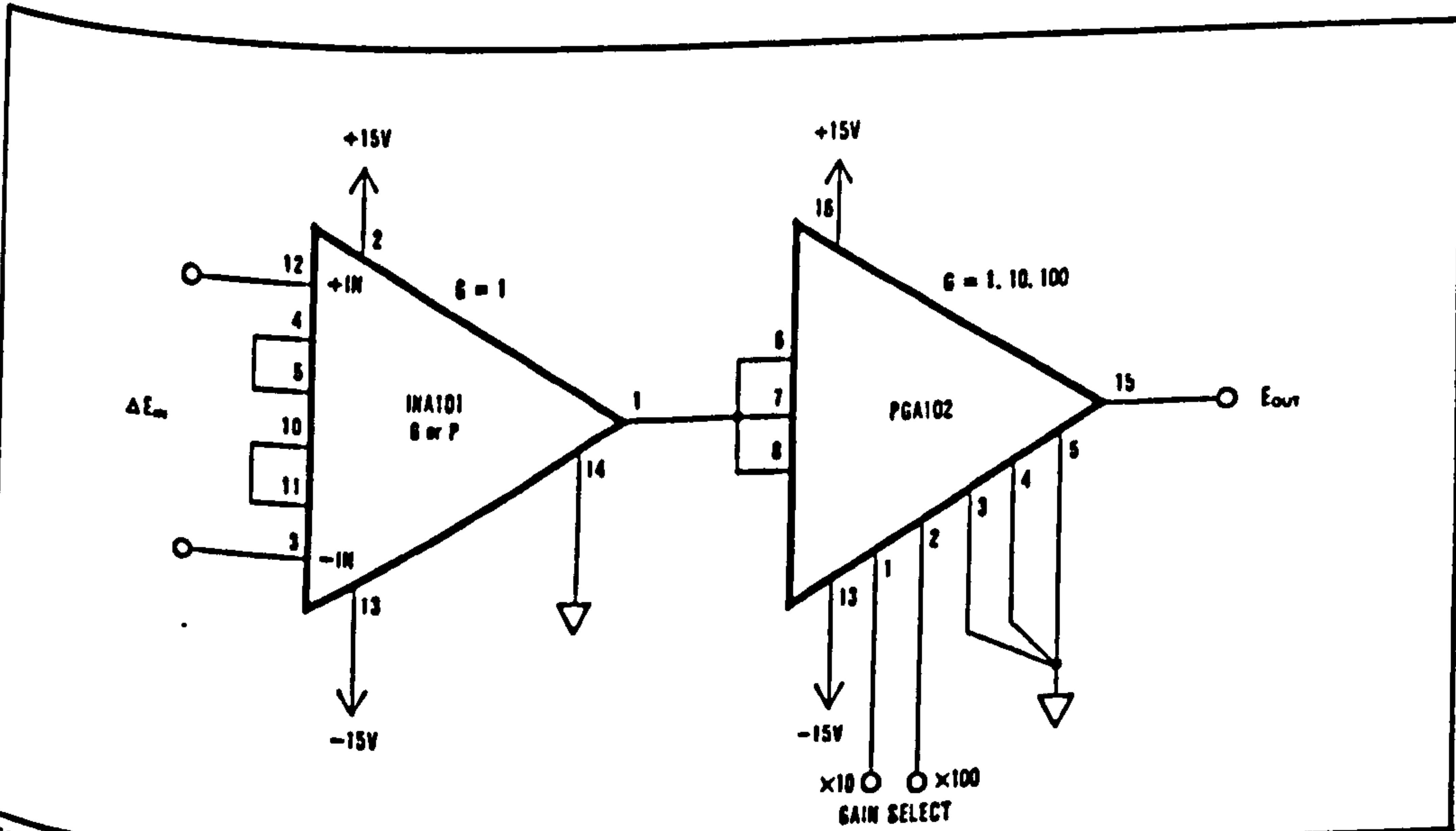


FIGURE 16. Programmable-Gain Instrumentation Amplifier Using the INA101 and PGA102.

GLOSSARY OF TERMS & DEFINITIONS

Instrumentation Amplifiers

COMMON-MODE INPUT IMPEDANCE

The effective impedance (resistance in parallel with capacitance) between either input of an amplifier and its common, or ground, terminal.

COMMON-MODE REJECTION (CMR)

When both inputs of a differential amplifier experience the same common-mode voltage (CMV), the output should, ideally, be unaffected. CMR is the ratio of the common-mode input voltage change to the differential input voltage (error voltage) which produces the same output change.

$$\text{CMR (in dB)} = 20 \log_{10} \text{CMV/Error Voltage}$$

Thus a CMR of 80dB means that 1V of common-mode voltage will cause an error of 100 μ V (referred to input).

COMMON-MODE REJECTION RATIO (CMRR)

The ratio of the differential voltage gain of an amplifier to its common-mode voltage gain.

COMMON-MODE VOLTAGE (CMV)

That portion of an input signal which is common to both inputs of a differential amplifier. Mathematically it is defined as the average of the signals at the two inputs:

$$\text{CMV} = e_1 + e_2 / 2$$

FEEDBACK

The return of a portion of the output signal from a device to the input of the device.

FULL POWER FREQUENCY RESPONSE

The maximum sinewave frequency at which a device can supply its peak-to-peak rated output voltage and current, without introducing significant distortion.

GAIN

The ratio of the output signal to the associated input signal of a device.

GAIN ERROR

The difference between the actual gain of an amplifier and the one predicted by the ideal gain expression.

INPUT BIAS CURRENT

The DC input current required at each input of an amplifier to provide zero output voltage when the input signal and input offset voltage are zero. The specified maximum is for each input.

INPUT BIAS CURRENT DRIFT

The rate of change of input bias current with temperature or time.

INPUT GUARDING

The use of an input shield that is sometimes driven to follow the voltage level of the input signal and, thereby, remove leakage and loss-inducing voltage differences between the input signal path and surrounding stray conduction paths.

INPUT OFFSET CURRENT

The difference of the two input bias currents in a differential amplifier.

INPUT OFFSET VOLTAGE

The DC input voltage required to provide zero voltage at the output of an amplifier when the input signal and input bias currents are zero.

INPUT PROTECTION

A means of protecting an input of a device from damage due to the application of excessive input voltage.

INSTRUMENTATION AMPLIFIER

A closed-loop differential input gain block exhibiting high input impedance and high common-mode rejection. Its primary function is to accurately amplify the voltage applied to its inputs.

NONLINEARITY

The peak deviation from a best straightline (curve fitting on input-output graph) expressed as a percent of peak-to-peak full scale output.

OVERLOAD RECOVERY TIME

The time required for the output of an amplifier to return from saturation to linear operation, following the removal of an input overdrive signal.

SETTLING TIME

The time required, after application of a step input signal, for the output voltage to settle and remain within a specified error band around the final value.

SLEW RATE

The maximum rate of change of an output voltage when supplying the rated output.



Strain Gauge Amplifier P.C.B.

check

Stock No. 435-692

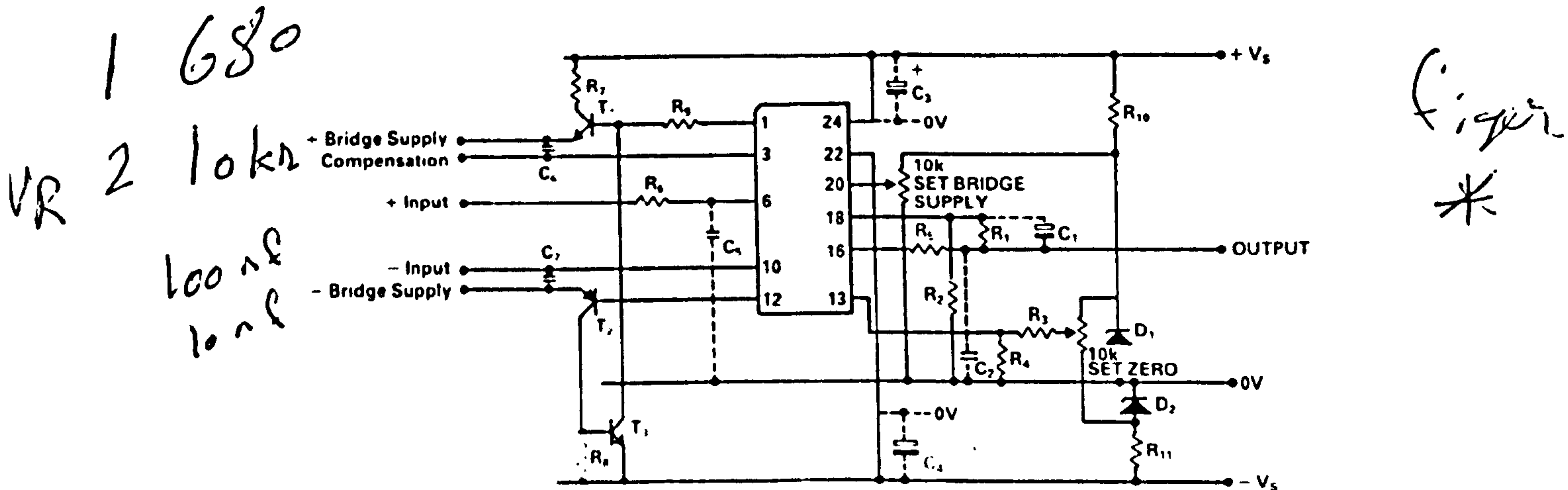
A printed circuit board to accept the RS Strain Gauge Amplifier and associated components to make an amplifier decoder for resistive bridge tyre sensors.

Assembly

All component positions are marked on the p.c.b., shorting links are indicated by solid lines.

The components list below includes p.c.b. mounting screw terminals for ease of connection, however these need not be used as wires can be directly soldered to the board.

Circuit Diagram



The values of R1 and R2 given below set the gain to 1000. The gain can be set to other values and is defined by the equation

$$\text{Gain} = 1 + \frac{R_1}{R_2}$$

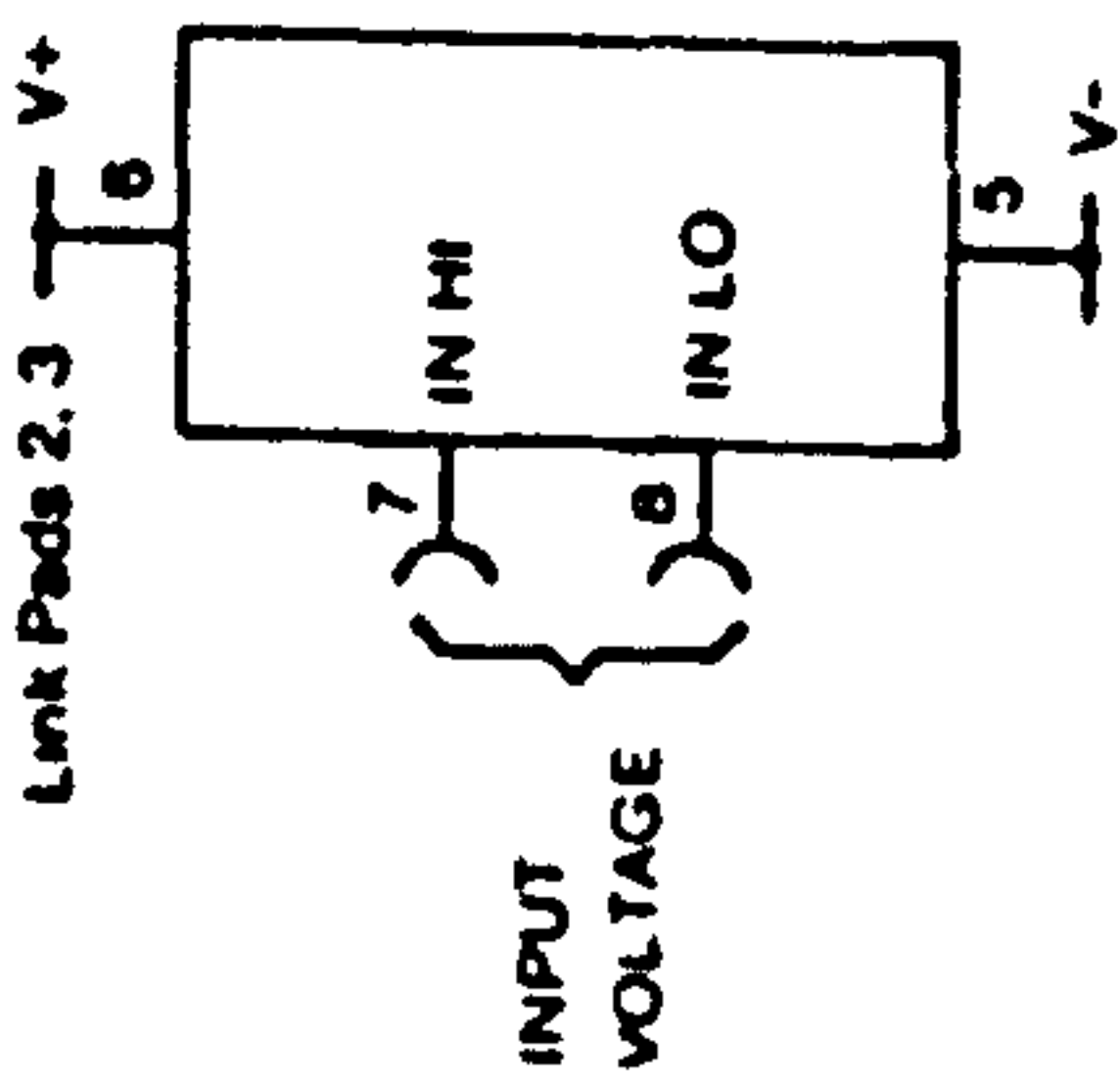
C5, C6 and C7 are for reduction of noise and considerably slow the output response. In some applications these components are best removed.

Components List

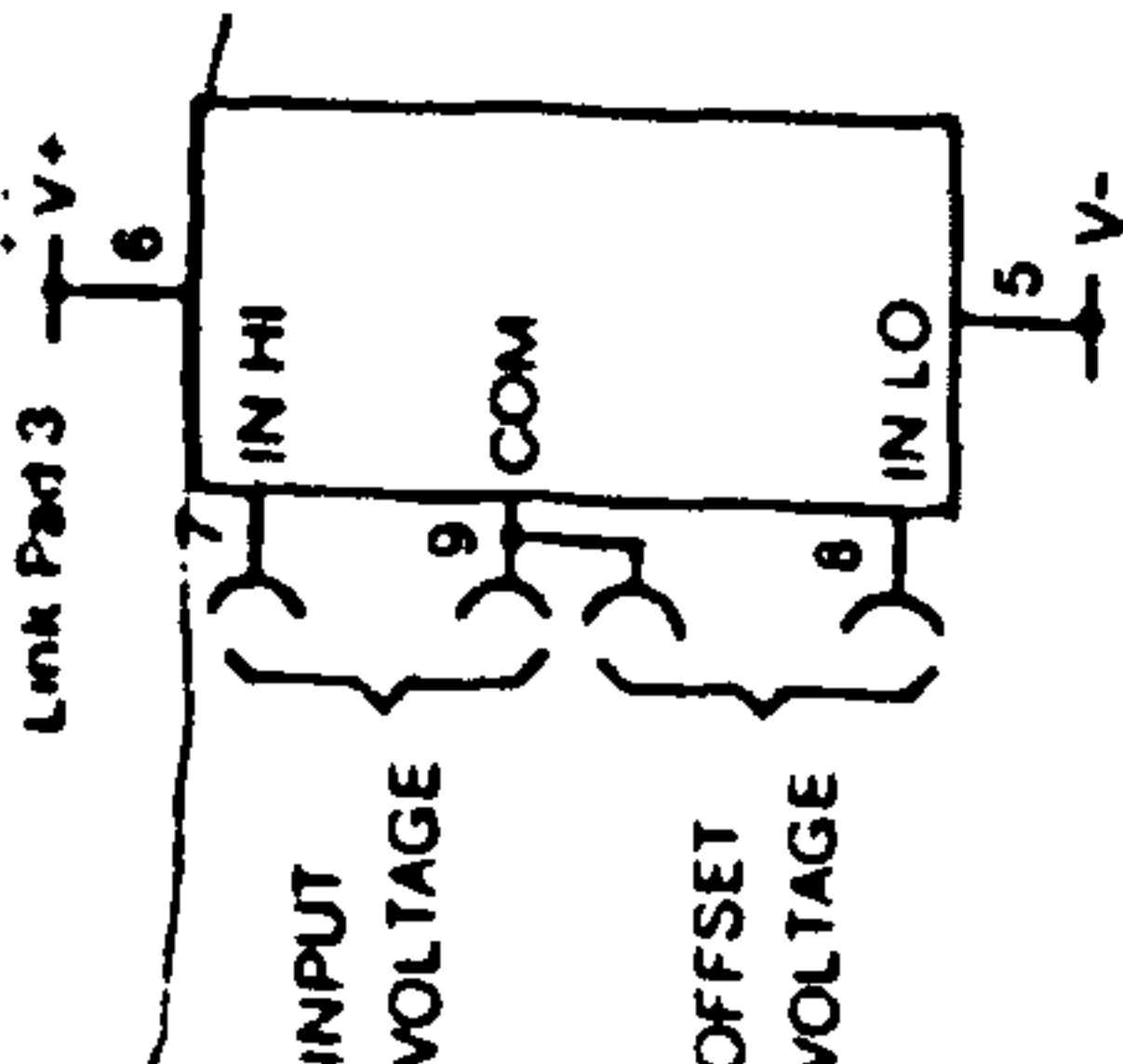
Component	Value	Stock No.	Quantity Required
R1 & R3	2 100K Ω	148-972	1 pk
R2 & R6	2 100 Ω	148-269	1 pk
R4	1 68 Ω	148-219	1 pk
R5 & R8	2 10 Ω	148-017	1 pk
R7	1 47 Ω	148-174	1 pk
R9	1 1K Ω	148-506	1 pk
R10 & R11	2 680 Ω	148-461	1 pk
VR1 & VR2	2 10K	186-520	2
D1 & D2	2 IN827	283-104	2
C1, C6 & C7	3 100 nF	114-840	1 pk
C2 & C5	2 10 nF	114-812	1 pk
C3 & C4	2 10 μ F	103-957	1 pk
T1	1 BD135 <i>BD139</i>	294-738	1 pk
T2	1 BD136 <i>BD140</i>	294-744	1 pk
T3	1 BC108	293-533	1 pk
4-Way Connector	-	423-762	1 pk
3-Way Connector	-	424-686	1 pk
IC Socket 24-pin	-	402-327	1 pk
Strain Gauge Amp	-	308-815	1

CIRCUIT INTERCONNECTIONS

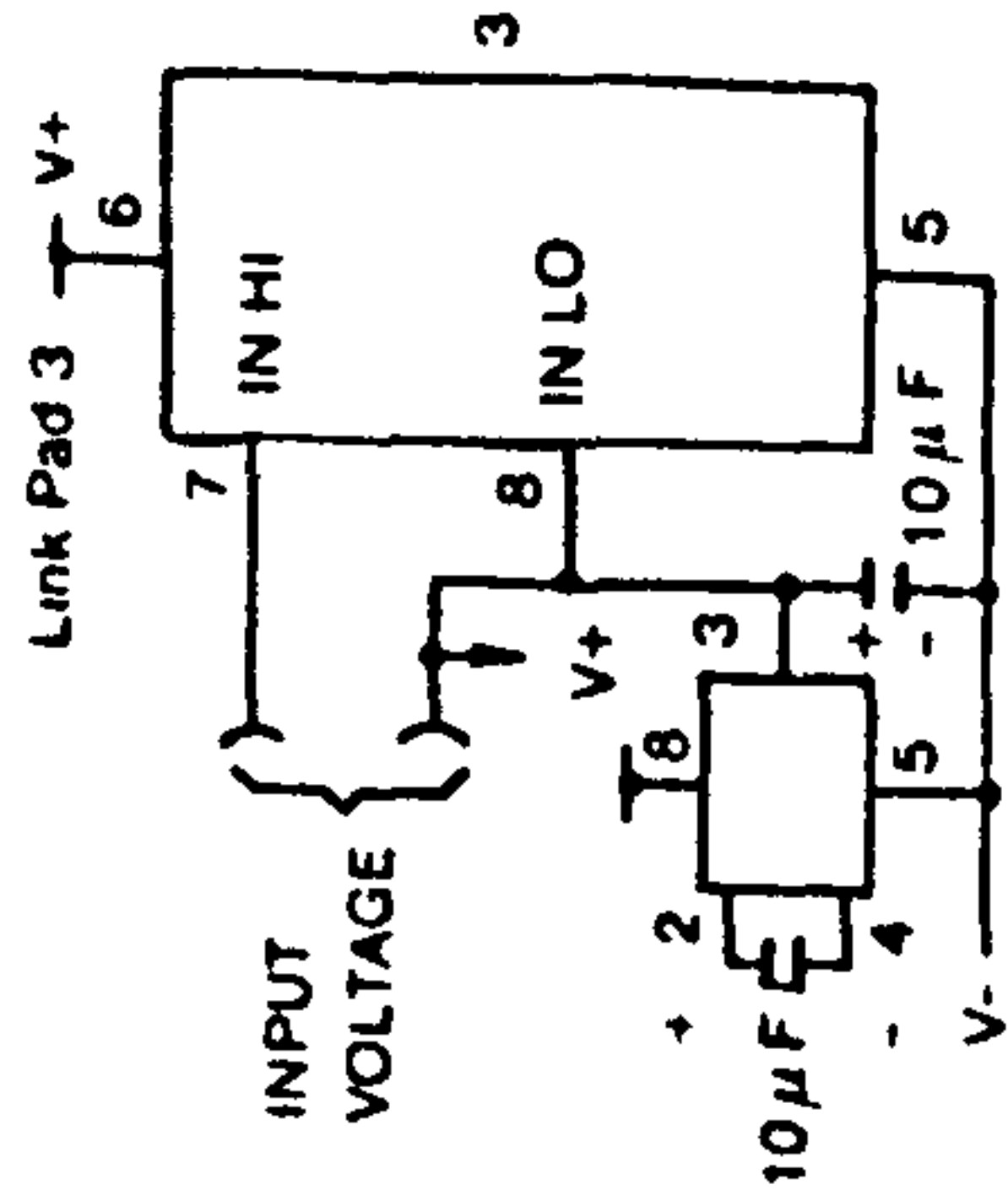
This DPM can be configured for any of the applications shown below. Interconnections can be made by one of two methods. 1: Via the user's conditioning PCB, terminating at the DPM edge connector or 2: Bridging solder across the appropriate solder pad links provided (see circuit diagram).



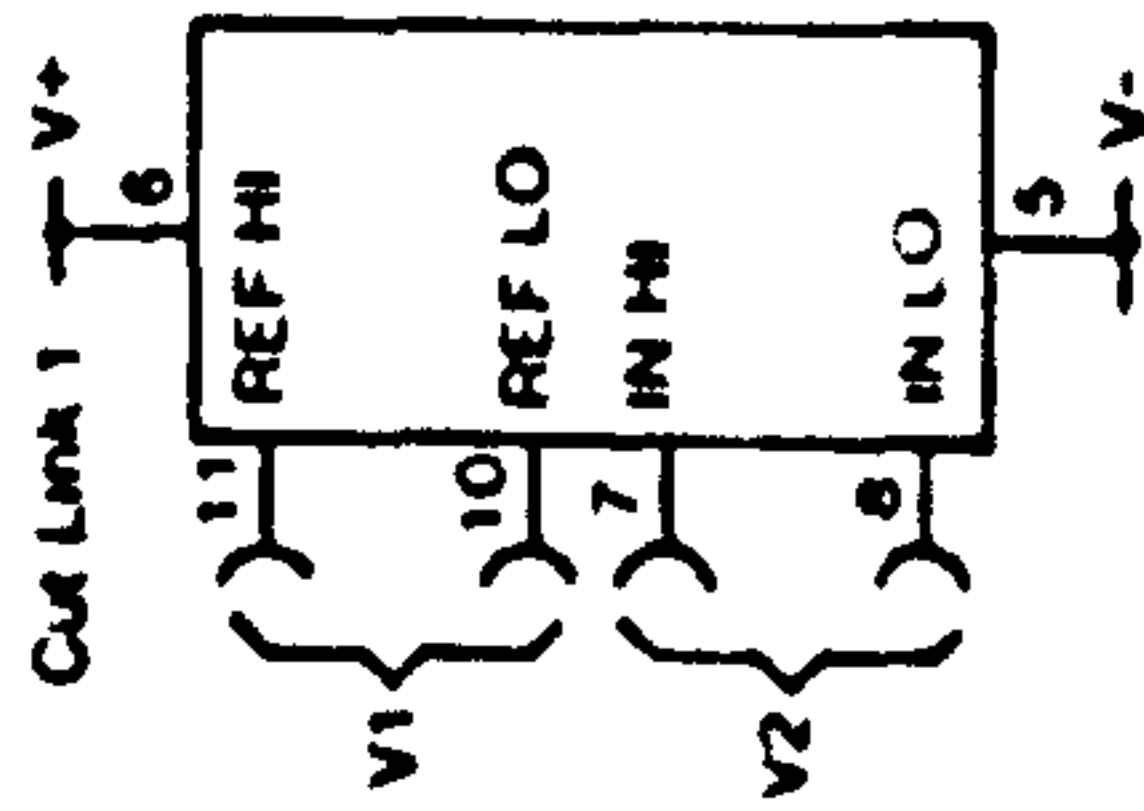
Measuring a floating voltage source of 200mV full scale.



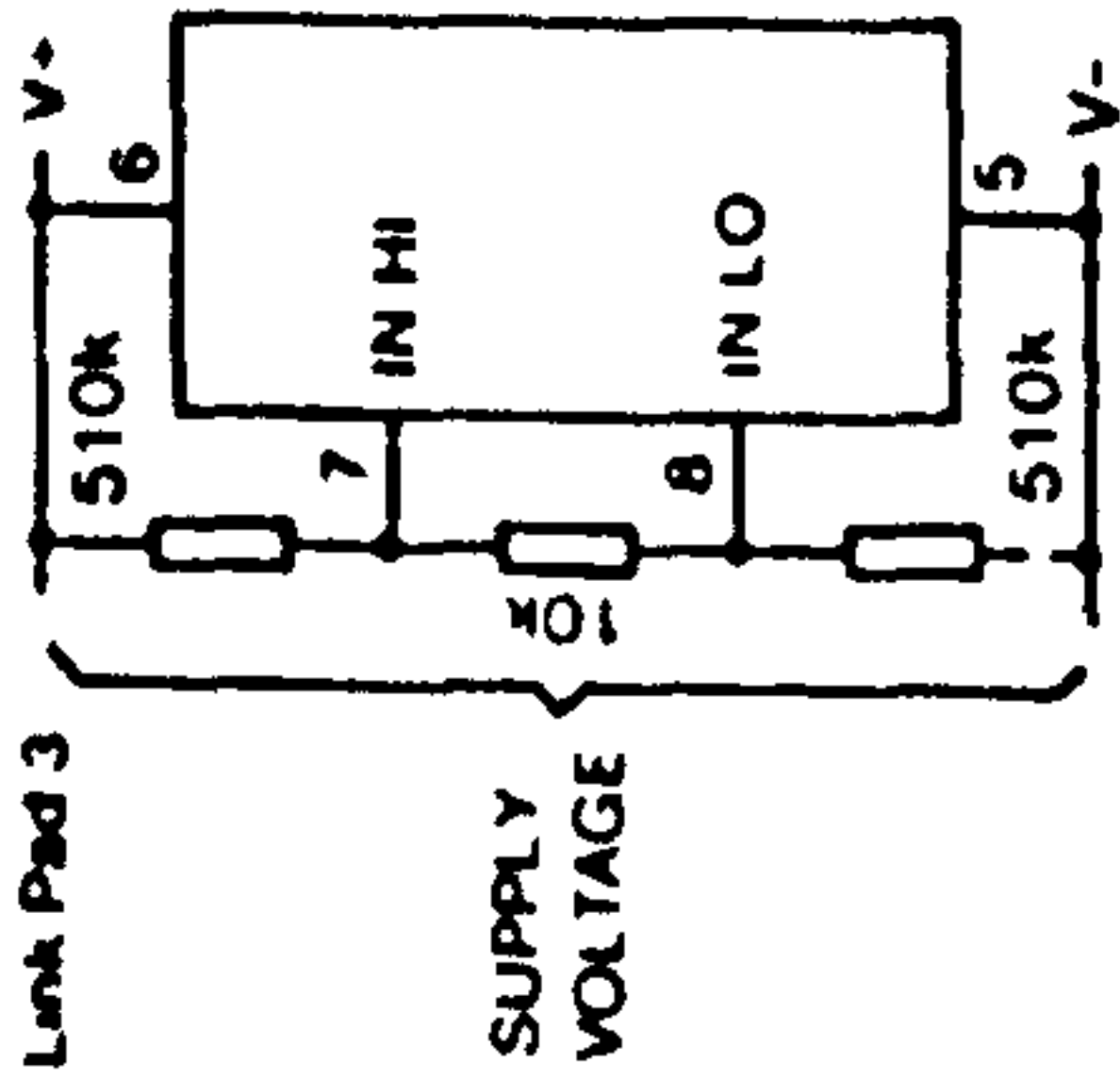
Zero display when the applied input is not zero, the offset and input voltages should be applied as shown.



Measuring a single ended input referenced to supply.



Measuring the ratio of two voltages. Reading = 1000 V2/V1.



Measuring a supply voltage (min 7.5V, max 15V).

PANEL FITTING

Fit the bezel to the front of the panel and then locate the meter into the bezel from behind. Alternatively the meter and bezel may be assembled before fitting into the front of the panel but care must be taken not to use excessive force.



3 1/2 Digit LCD DPM

Stock No. 257-212

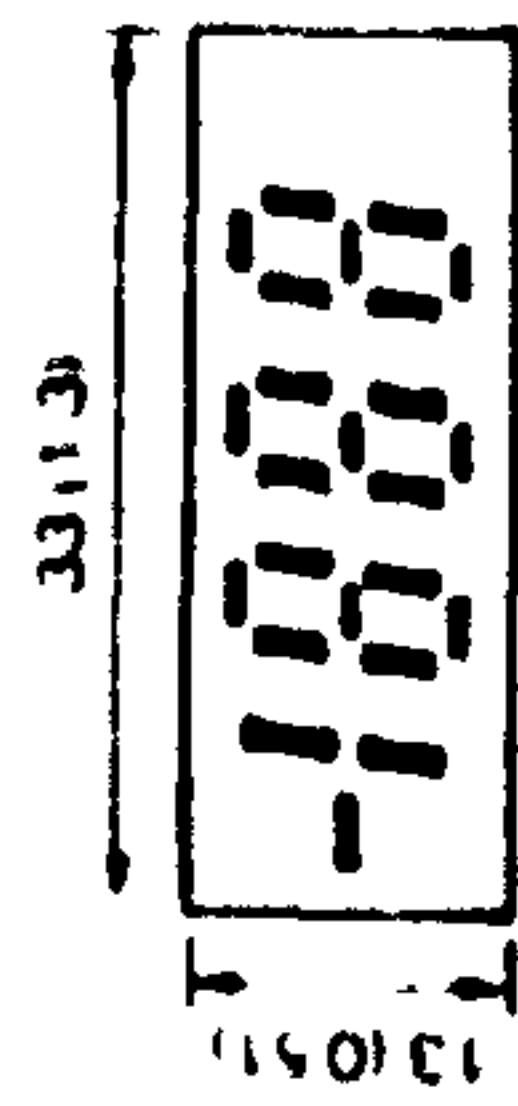
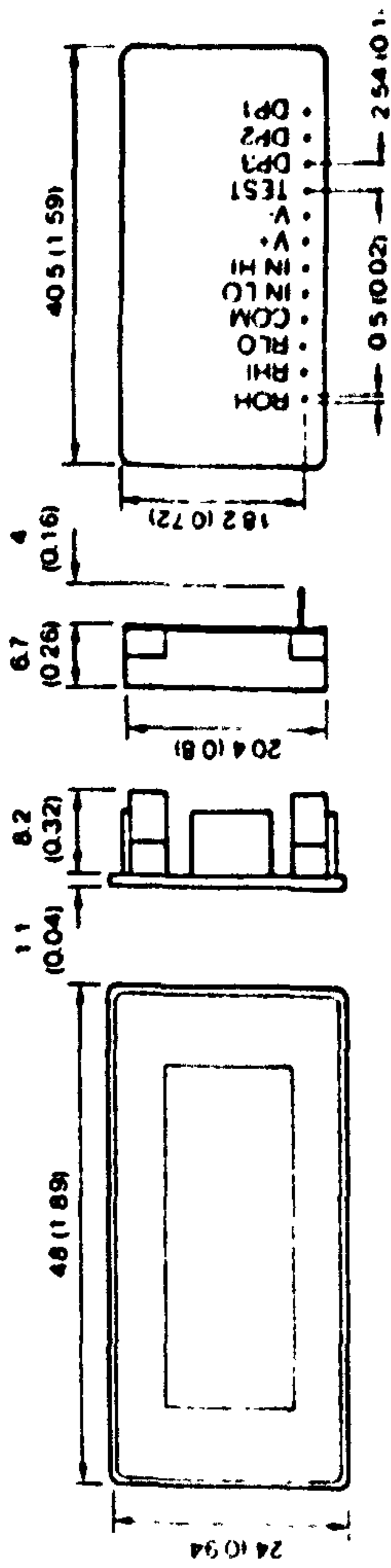
FEATURES:

- △ Ultra Compact
- △ 12.5 mm Digits
- △ Ultra Low Power
- △ Snap in Bezel

A uniquely compact LCD DPM ideally suited for low or high volume applications featuring an exceptionally large display in a sub-miniature package. The meter will plug directly into a SIL socket or can be panel mounted using the snap-in bezel provided. The low profile bezel incorporates a flat reverse printed window giving a superb appearance that cannot be damaged or rubbed off by contact.

This DPM features Auto-zero, Auto-polarity, 200mV FSD, 12.5mm Digit height, Low battery indication and logic selectable decimal points. On-card solder pads for essential inter-connections make selection of operating mode quick and easy with the minimum of external wiring. Very low current consumption allows long battery life making it especially useful in portable equipment.

SPECIFICATION	MIN	TYP	MAX	UNIT
Accuracy (± 1 count)		0.05	0.1	%
Linearity			± 1	Count
Sample Rate		3		per sec
Temp Stability		100		ppm/°C
Temp Range	0		50	°C
Supply Voltage	7.5	9	15	V
Supply Current		150		μ A
Max DC Input Voltage			± 20	V
Input Leakage Current (VIN=0V)		1	10	pA
Low Battery Threshold		7.5		V

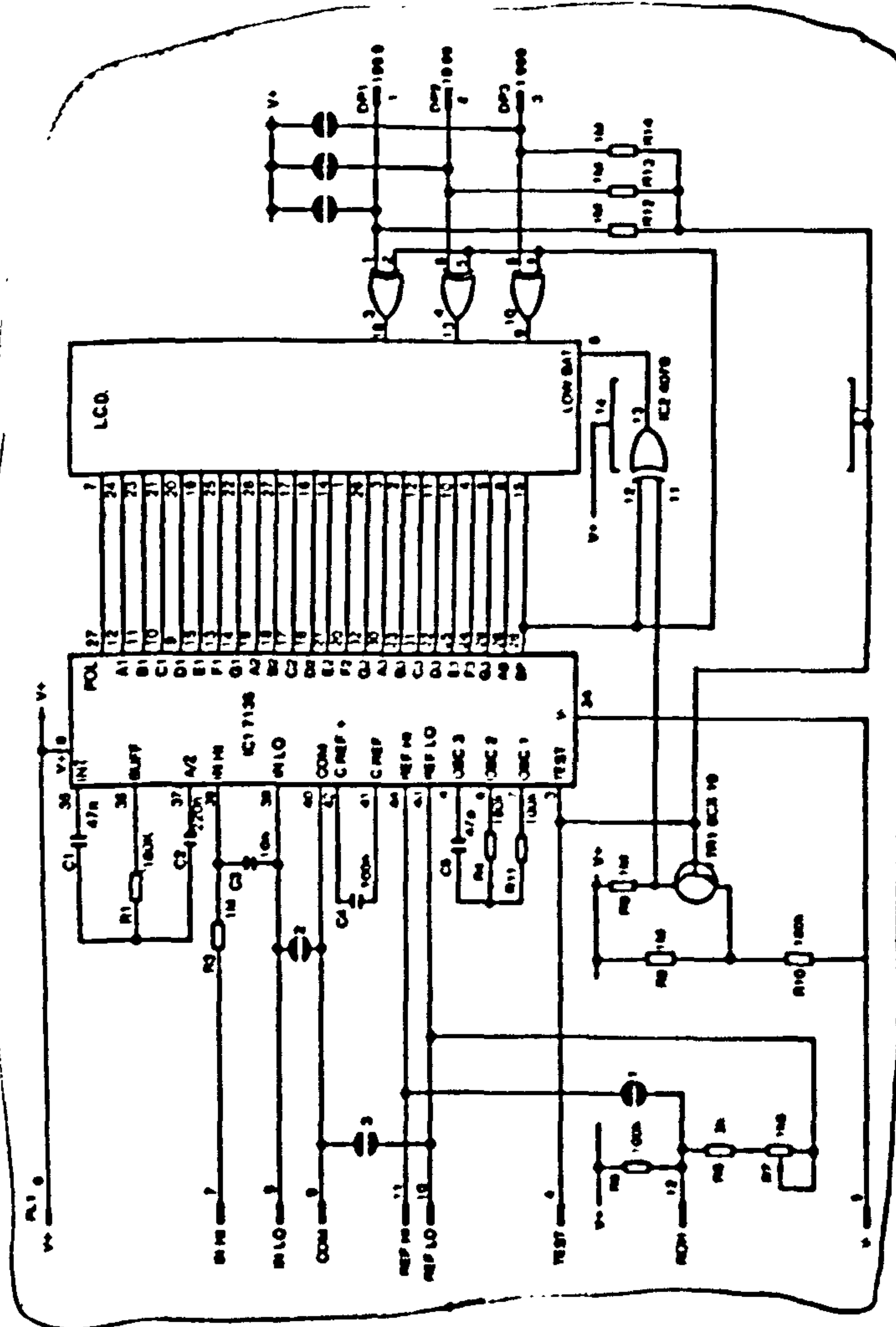


Display in TEST mode

Panel cut-out 45 x 22.2 (1.77 x 0.87)

PIN FUNCTION

1. DP1: Connect to V+ to display 199.9.
2. DP2: Connect to V+ to display 19.99.
3. DP3: Connect to V+ to display 1.999.
4. TEST: Connect to V+ to turn on segments as illustrated. It should not be operated for more than a few seconds as the DC voltage applied to the LCD may "burn" the display. This pin is normally at 5 Volts below V+ and is the ground for the digital section of the meter. It can be used to power external logic up to a maximum of 1mA.
5. V-: Negative power supply.
6. V+: Positive power supply.
7. IN HI: Positive measuring input.
8. IN LO: Negative measuring input.
9. COM: The ground for the analogue section of the converter, held actively at 2.8V (Nom) below V+. COM must not be allowed to sink excessive current (>100 μ A) by connecting it directly to a higher voltage.
10. REF LO: Negative input for the reference voltage (can be connected to common via Link 3).
11. REF HI: Positive input for reference voltage (connected via Link 1 to Ref out).
12. REF OUT: Positive output from internal reference.



ANALOGUE INPUTS

IN HI, IN LO, REF HI and REF LO are true differential inputs. They respond to the voltage across them and not their voltage with respect to the power supply.

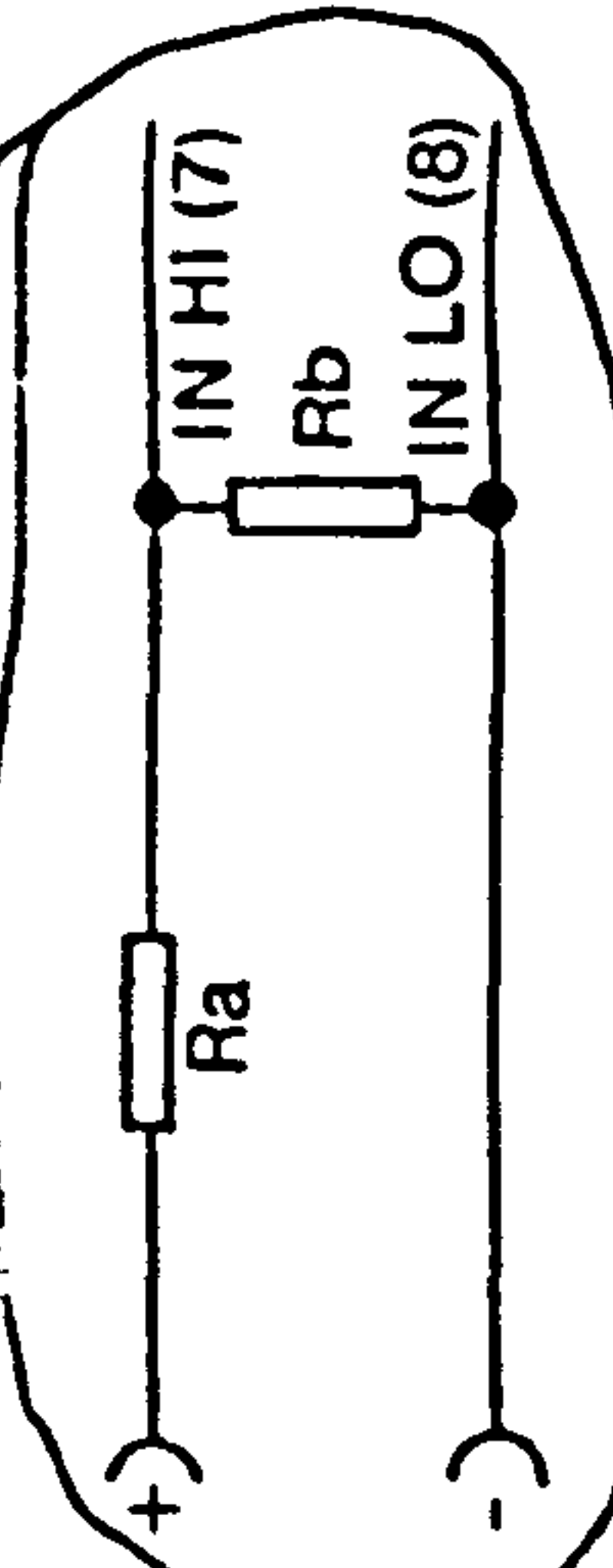
There is a limit to this however, known as the Common Mode range. Any input must be no higher than V+ -0.5V and no lower than V-, +1.0V. If the power supply is floating with respect to the circuit being monitored connect IN LO and REF LO to AN COM for best results. If there is a danger that any input may be taken beyond the power supply rails, a series resistor must be fitted to limit the input current to less than 100 μ A.

APPLICATIONS

Input Scaling: Two resistors can be used to alter the full scale reading of the meter. See table.

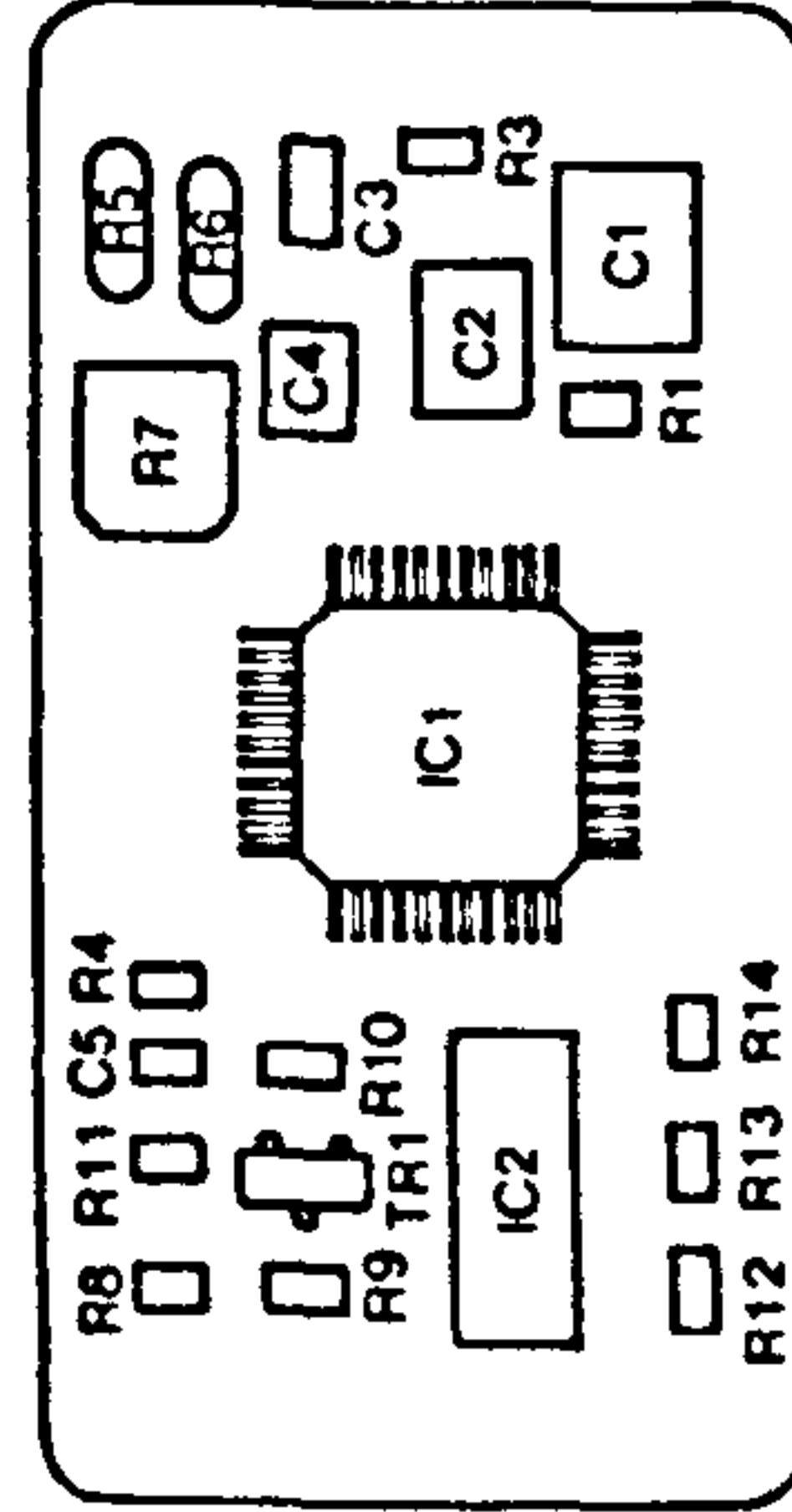
INPUT SCALING

The following resistor values are recommended for changing the f.s.d. of the meter.



Required F.S.D.	Ra	Rb
2V	910k	100k
20V	1M	10k
200V	1M	1k
2000V	1M	100R
200 μ A	Link	1k
2mA	Link	100R
20mA	Link	10R
200mA	Link	1R

COMPONENT LAYOUT

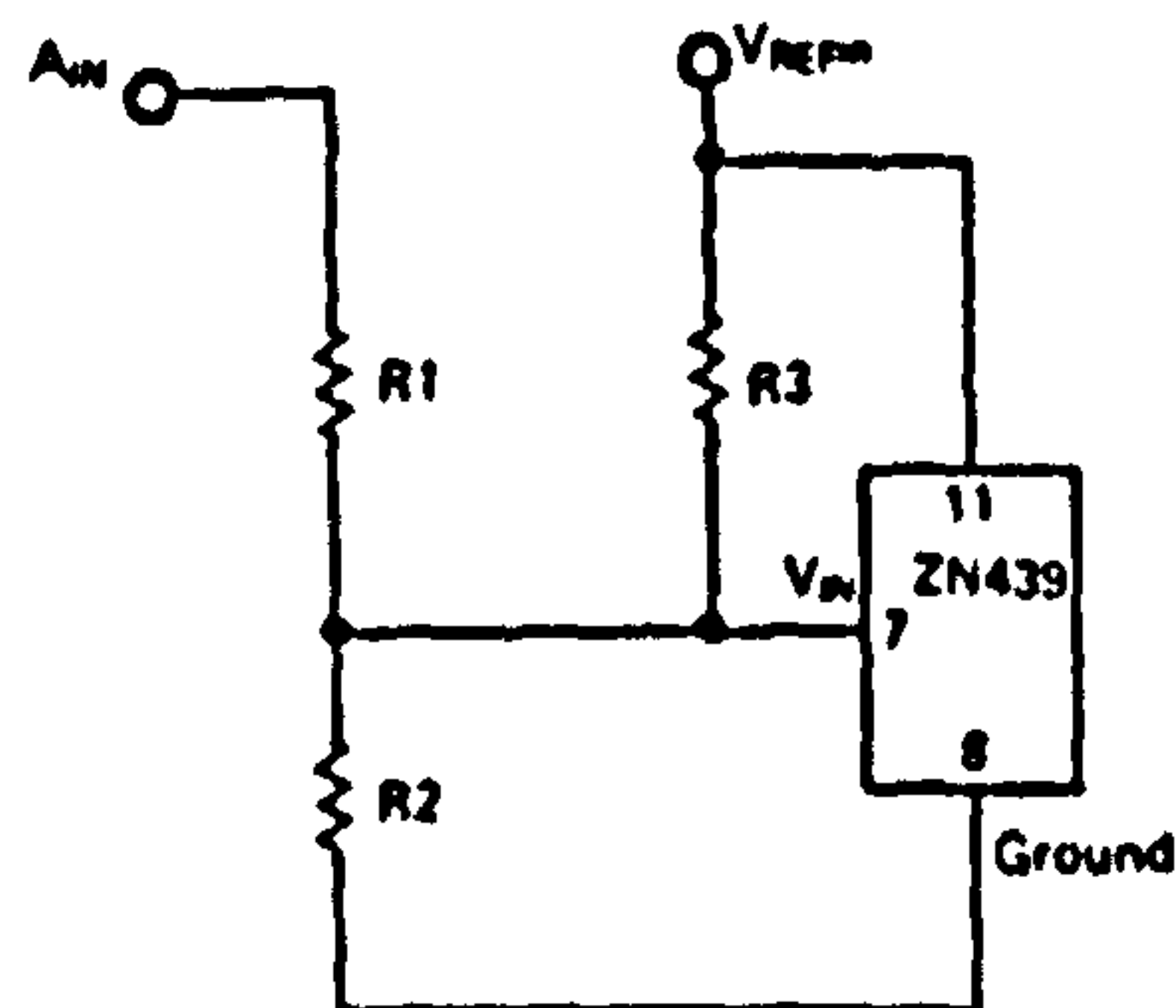


4- A/D Converter

Unipolar logic coding

Analogue input (A_{IN}) (Nominal code centre value)	Output code (Binary)
FS - 1LSB	11111111
FS - 2LSB	11111110
$\frac{3}{4}$ FS	11000000
$\frac{1}{2}$ FS + 1LSB	10000001
$\frac{1}{2}$ FS	10000000
$\frac{1}{2}$ FS - 1LSB	01111111
$\frac{1}{4}$ FS	01000000
1LSB	00000001
0	00000000

Figure 22 Basic bipolar input connection



Bipolar operation

For bipolar operation the input to the ZN439 is offset by half full-scale by connecting a resistor R_3 between $V_{REF IN}$ and V_{IN} (Figure 22).

When $A_{IN} = -FS$, V_{IN} needs to be equal to zero.

When $A_{IN} = +FS$, V_{IN} needs to be equal to $V_{REF IN}$.

If the full-scale range is $\pm G$, $V_{REF IN}$ then $R_1 = (G - 1)$, R_2 and $R_1 = G$, R_3 fulfills the required conditions.

To match the ladder resistance, $R_1/R_2/R_3 (= R_{IN}) = 2.7k$.

Thus the nominal values of R_1 , R_2 , R_3 are given by $R_1 = 5.4Gk$, $R_2 = 5.4G/(G - 1)k$, $R_3 = 5.4k$.

A bipolar range of $\pm V_{REF IN}$ (which corresponds to the basic unipolar 0 to $V_{REF IN}$) results if $R_1 = R_3 = 5.4k$ and $R_2 = \infty$.

Assuming the $V_{REF IN} = 2.5V$ the nominal values of resistors for $\pm 5V$ and $\pm 10V$ input ranges are given in the following table.

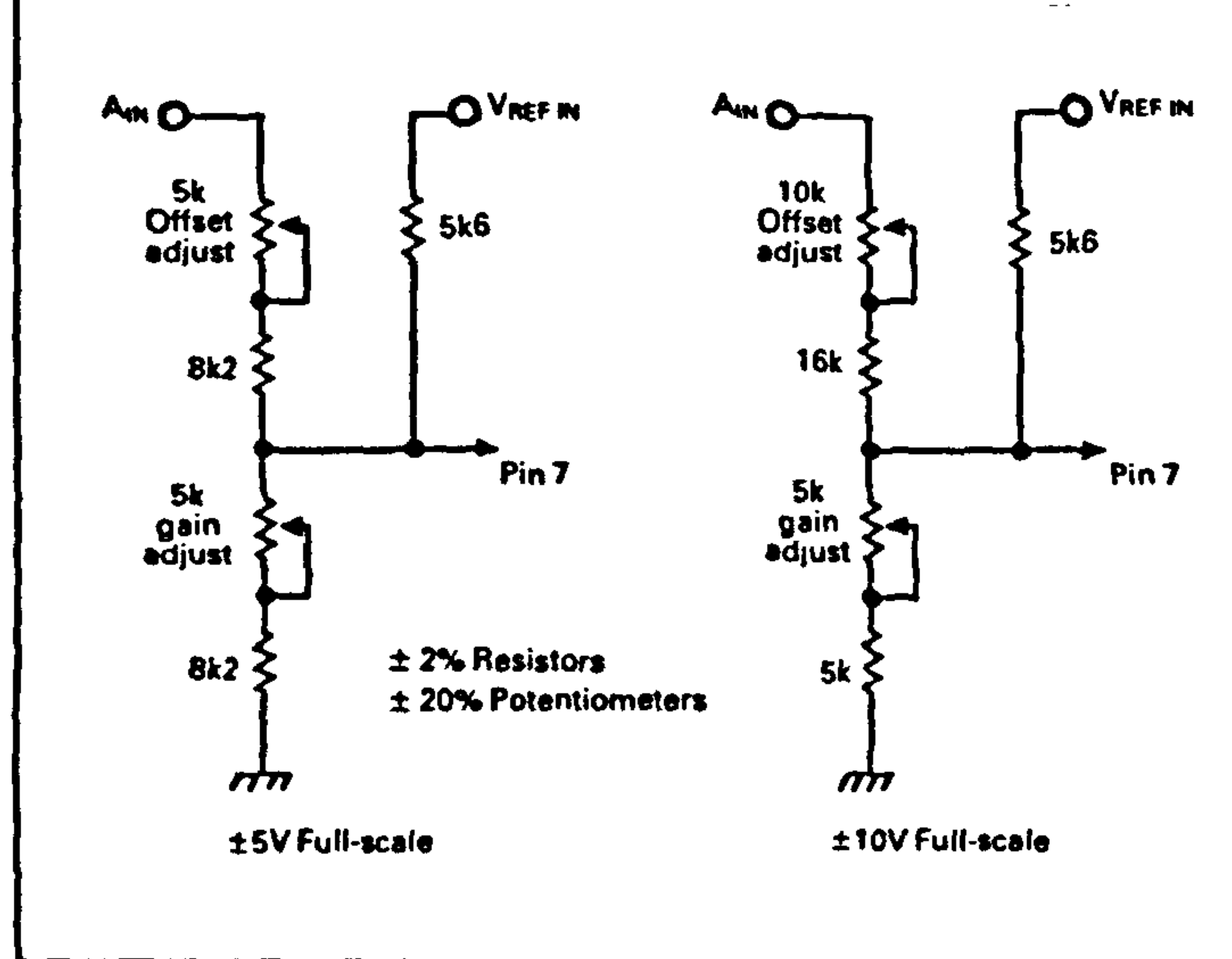
Input range	G	R_1	R_2	R_3
$\pm 5V$	2	10.8k	10.8k	5.4k
$\pm 10V$	4	21.6k	7.2k	5.4k

Minus full-scale (offset) is set by adjusting R_1 about its nominal value relative to R_3 . Plus full-scale (gain) is set by adjusting R_2 relative to R_1 . Practical circuit realisations are given in Figure 23.

Bipolar adjustment procedure

- (i) Apply continuous WR pulses at intervals long enough to allow a complete conversion and monitor the digital outputs.

Figure 23 Bipolar operation



Offset setting

- (ii) Apply $-(FS - \frac{1}{2}LSB)$ to A_{IN} and adjust offset until the bit 8 (LSB) output just flickers between 0 and 1 with all other bits at 0.

i.e. for transition 00000000 to 00000001.

Gain setting

- (iii) Apply $+(FS - 1\frac{1}{2}LSB)$ to A_{IN} and adjust gain until bit 8 (LSB) just flickers between 0 and 1 with all other bits at 1.

i.e. for transition 11111111 to 11111110.

Bipolar setting-up points

Input range, $\pm FS$	$-(FS - \frac{1}{2}LSB)$	$+(FS - 1\frac{1}{2}LSB)$
$\pm 5V$	-4.9805V	+4.9414V
$\pm 10V$	-9.9609V	$\pm 9.8828V$

$$1LSB = \frac{2FS}{256}$$

Bipolar logic coding

Analogue input (A_{IN}) (Nominal code centre value)	Digital output code	
	MSB	LSB
$+(FS - 1LSB)$	11111111	
$+(FS - 2LSB)$	11111110	
$+\frac{1}{2}FS$	11000000	
+1LSB	10000001	
0	10000000	
-1LSB	01111111	
$-\frac{1}{2}FS$	01000000	
$-(FS - 1LSB)$	00000001	
-FS	00000000	

Figure 15 Comparator equivalent circuit

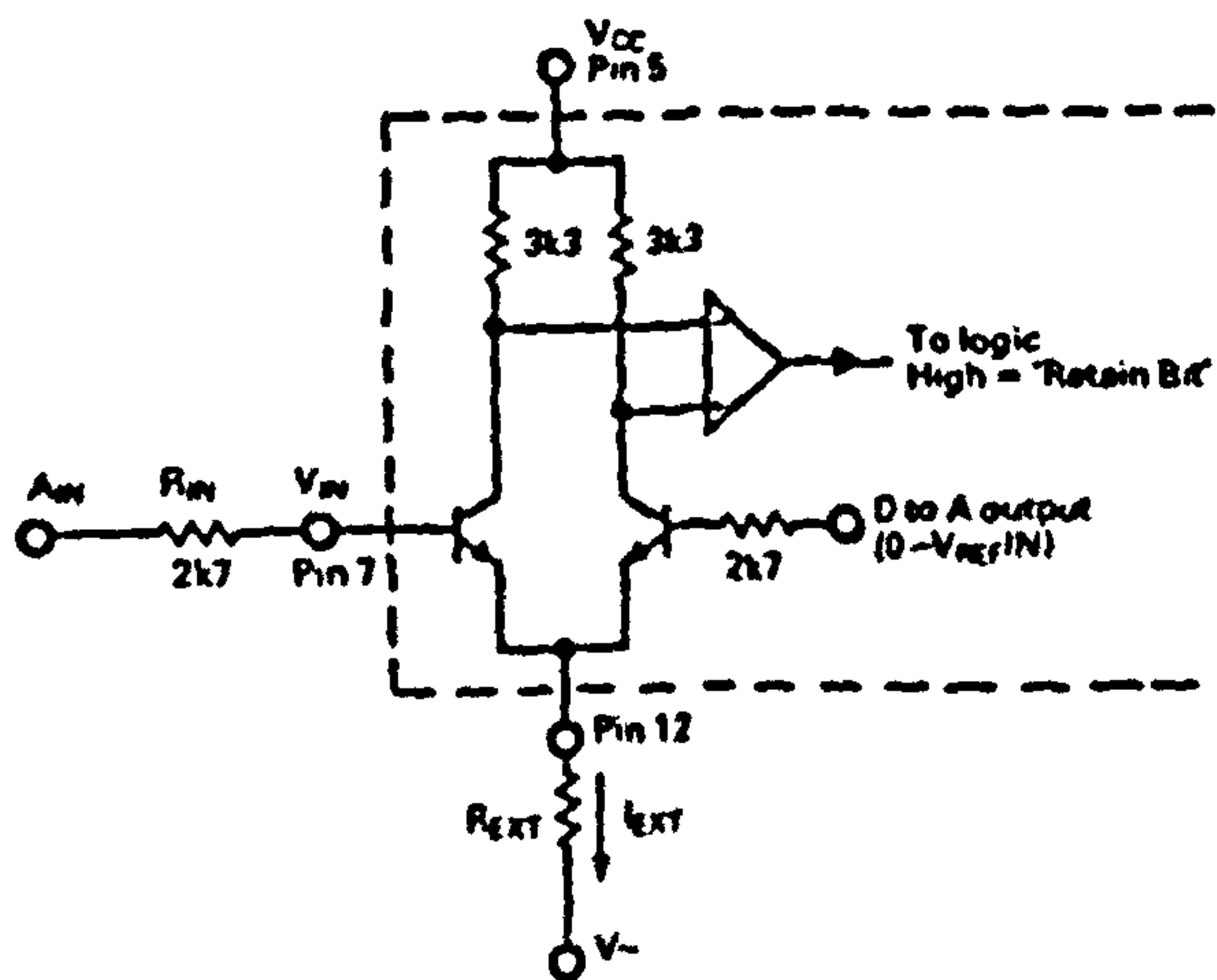


Table 1

V ₋ (Volts)	R _{EXT} (kΩ)
3	47
5	82
10	150
12	180
15	220
20	330
25	390
30	470

D-A converter

The converter is of the voltage switching type and uses an R-2R ladder network as shown in Figure 18. Each element is connected to either 0V or V_{REF IN} by transistor voltage switches specially designed for low offset voltage (1 millivolt).

A binary weighted voltage is produced at the output of the R-2R ladder:

$$D \text{ to A output} = \frac{n}{256} (V_{REF IN} - V_{os}) + V_{os}$$

where n is the digital input to the D to A from the successive approximation register.

V_{os} is a small offset voltage that is produced by the device supply current flowing in the package lead resistance. This offset will normally be removed by the setting up procedure and since the offset temperature coefficient is low (7ppm/°C) the effect on accuracy will be negligible.

The D to A output range can be considered to be 0 - V_{REF IN} through an output resistance R(2k7).

Figure 16 Diode pump circuit

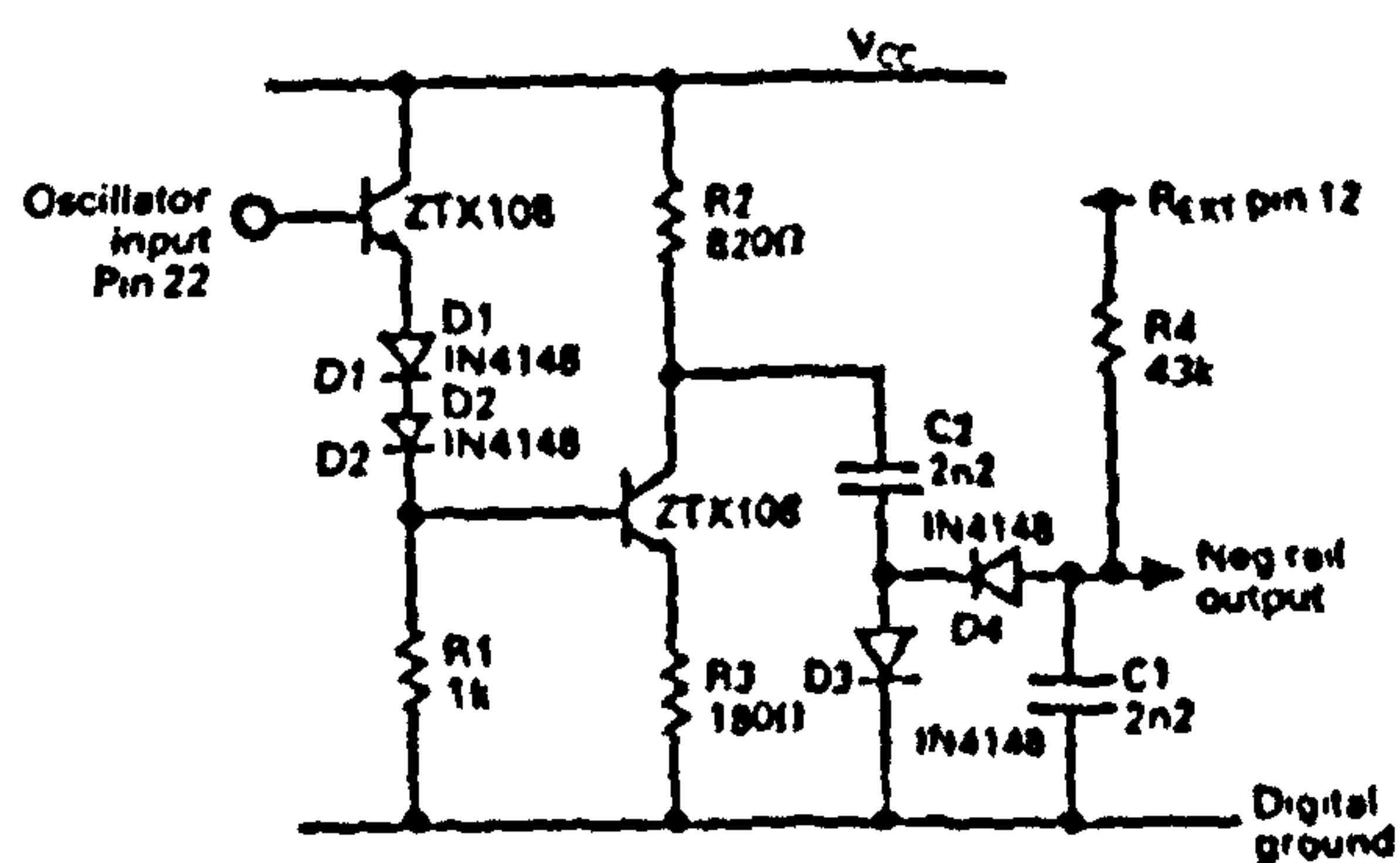


Figure 17 Diode pump circuit to supply comparator tail current for up to five ZN439's

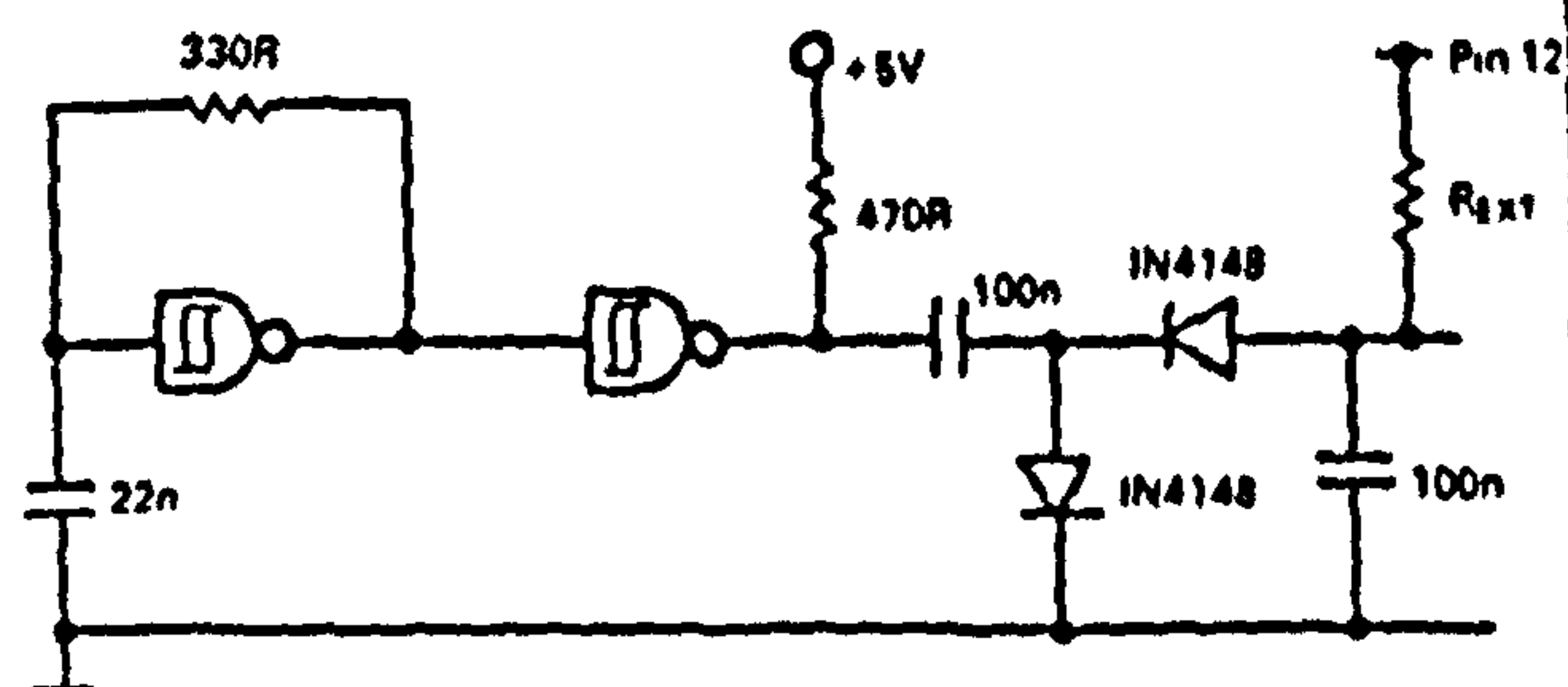
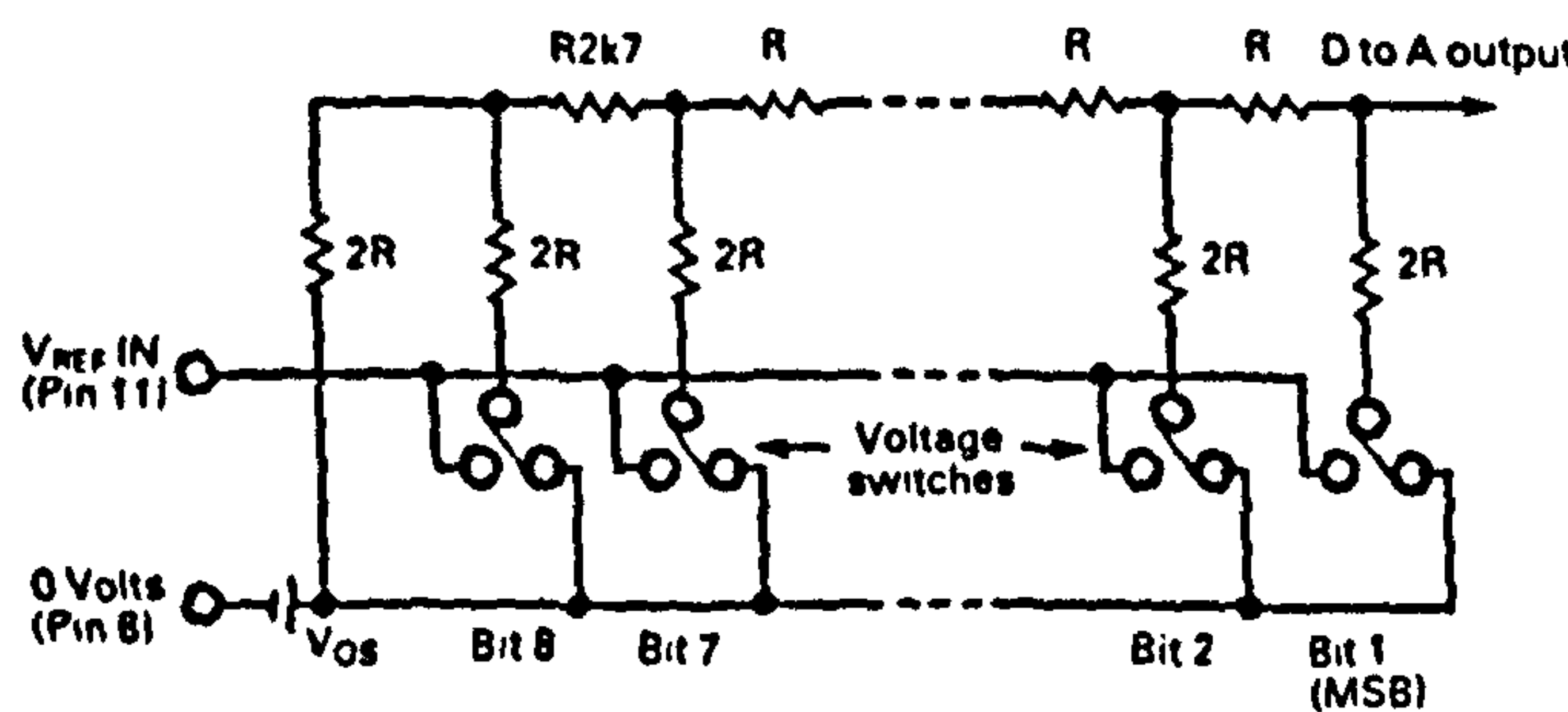


Figure 18 R-2R ladder network



Analogue input ranges

The basic connection of the ZN439 shown in Figure 19 has an analogue input range 0 to V_{REF IN} which, in some applications, may be made available from previous signal conditioning/scaling circuits. Input voltage ranges greater than this are accommodated by providing an attenuator on the comparator input, whilst for smaller input ranges the signal must be amplified to a suitable level.

Bipolar input ranges are accommodated by offsetting the analogue input ranges so that the comparator always sees a positive input voltage.

A suitable circuit is shown in Figure 16. This circuit can be used in any converter operation mode. The diode pump circuit shown in Figure 16 is driven by the on-chip clock (pin 22) and applies a voltage of about -3V to R₄, thus providing the tail current for the comparator.

Where several ZN439's are used in a system the self-oscillating diode pump circuit of Figure 17 is recommended. Alternatively, if a negative supply is available in the system then this may be utilised. A list of suitable resistors for different supply voltages is given in Table 1.

General circuit operation

The ZN439 utilises the successive approximation technique to produce an 8-bit parallel digital output. Upon receipt of a negative going pulse on the \overline{WR} input the status output goes high, and the DAC input is set to the MSB. The resulting analogue output is compared with the unknown analogue input signal by means of the comparator. If the analogue input is larger, the MSB is left in circuit and if not the MSB is removed. On the second clock pulse this sequence is repeated for the next most significant bit and so on until all the 8 bits have been compared. On the 8th negative clock edge status goes low indicating that the conversion is complete.

The double-buffered register means the outputs can be enabled at any time, irrespective of the conversion status, and valid data will always be presented to the data bus. Therefore the \overline{RD} signal can be completely asynchronous with respect to the status. Data can be read by taking \overline{RD} low, thus enabling the 3-state outputs. \overline{RD} cannot be tied low as this will prevent the converter from updating its outputs at the end of a conversion.

Figure 2 Typical external components

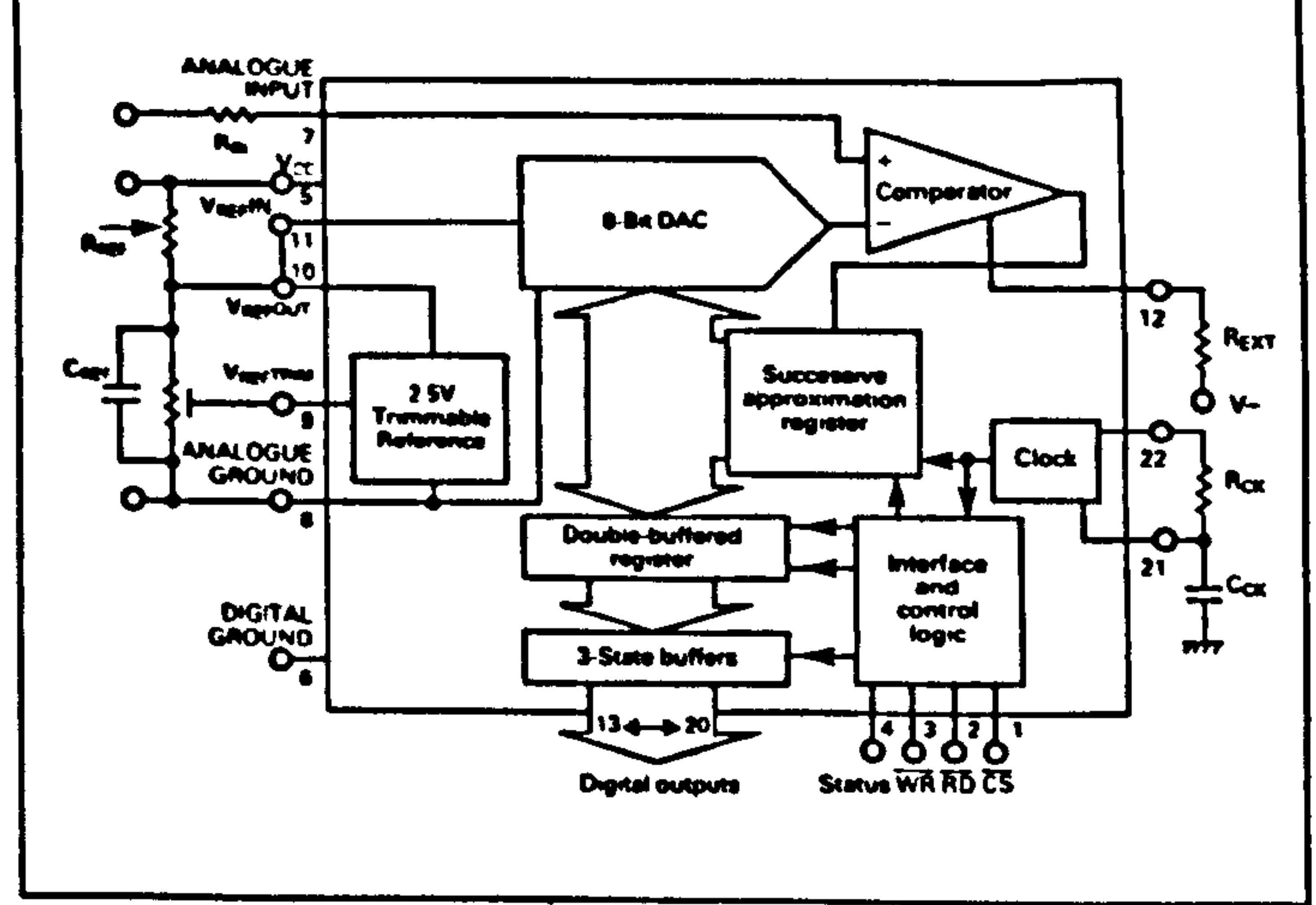
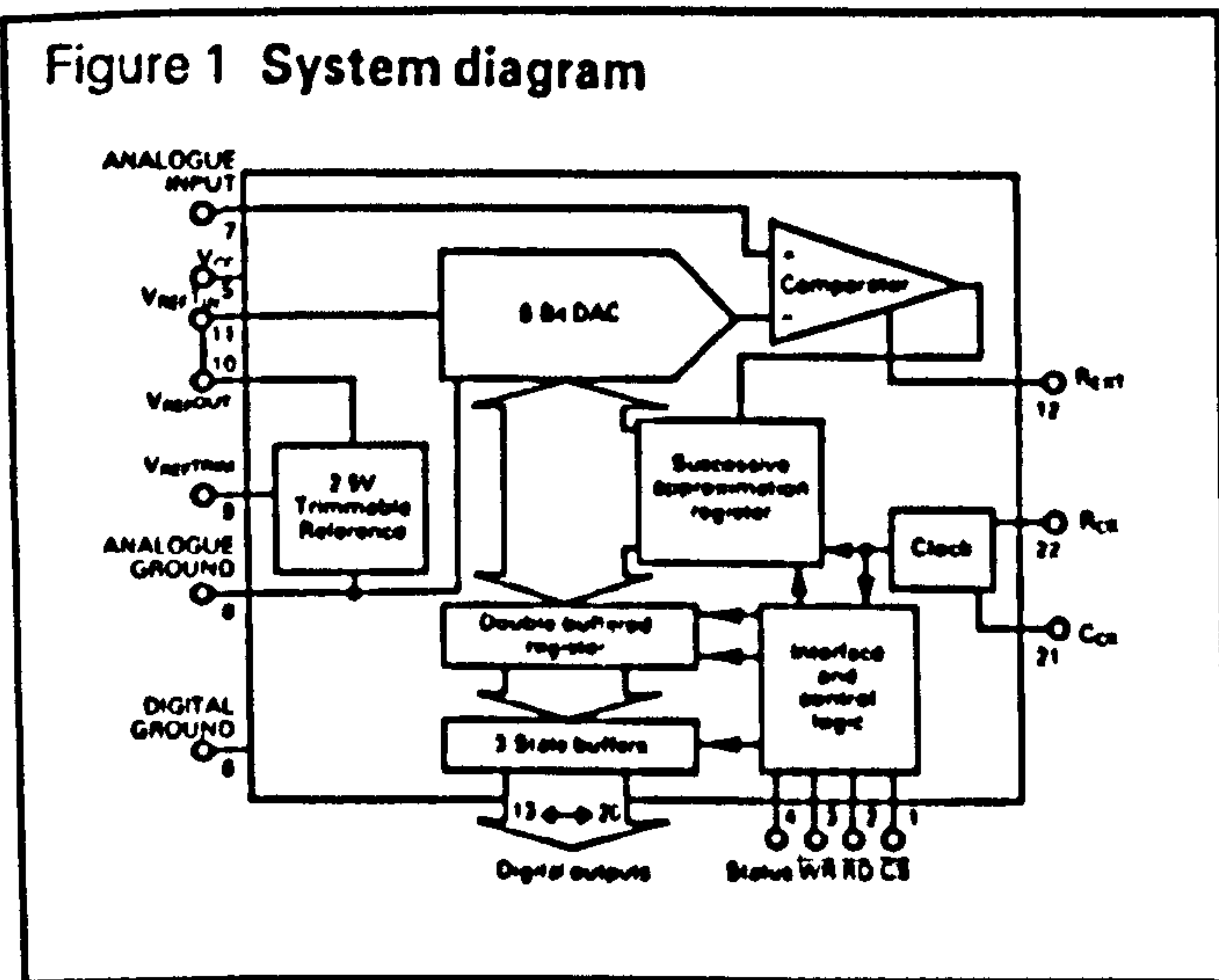


Figure 1 System diagram



Conversion timing

The ZN439 will accept a low going convert (\overline{WR}) pulse, which can be completely asynchronous with respect to the clock, and will produce valid data between 8 and up to 9 clock pulses later depending on the relative timing of the clock and convert signals. Timing diagrams for a conversion are shown in Figure 3.

The ZN439 is first selected by taking \overline{CS} (chip select) low. The converter is cleared by a low going convert (\overline{WR}) pulse, which sets the most significant bit and the status while resetting all other bits. Holding the \overline{WR} input low will not inhibit the operation of the device.

The convert (\overline{WR}) pulse can be as short as 150ns; however the MSB must be allowed to settle for at least 625ns before the MSB decision is made. To ensure that this criterion is met even with short write pulses the converter waits for a falling clock edge before commencing with the conversion. This ensures that the MSB is allowed to settle for at least a full clock period or 625ns at maximum clock frequency. If the \overline{WR} input is pulsed low at any time the conversion will restart. The input signals can be

Figure 3 Timing diagrams

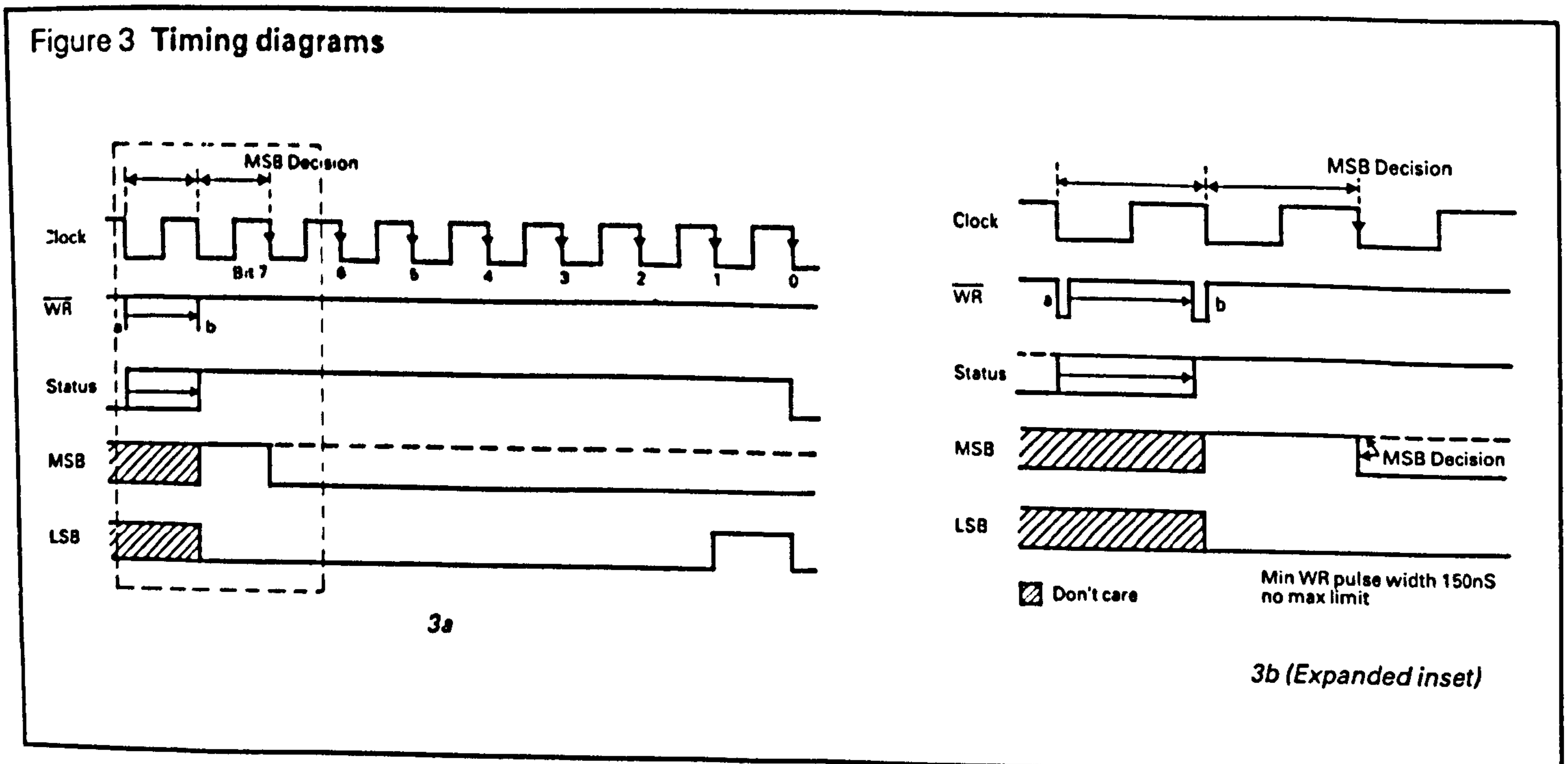
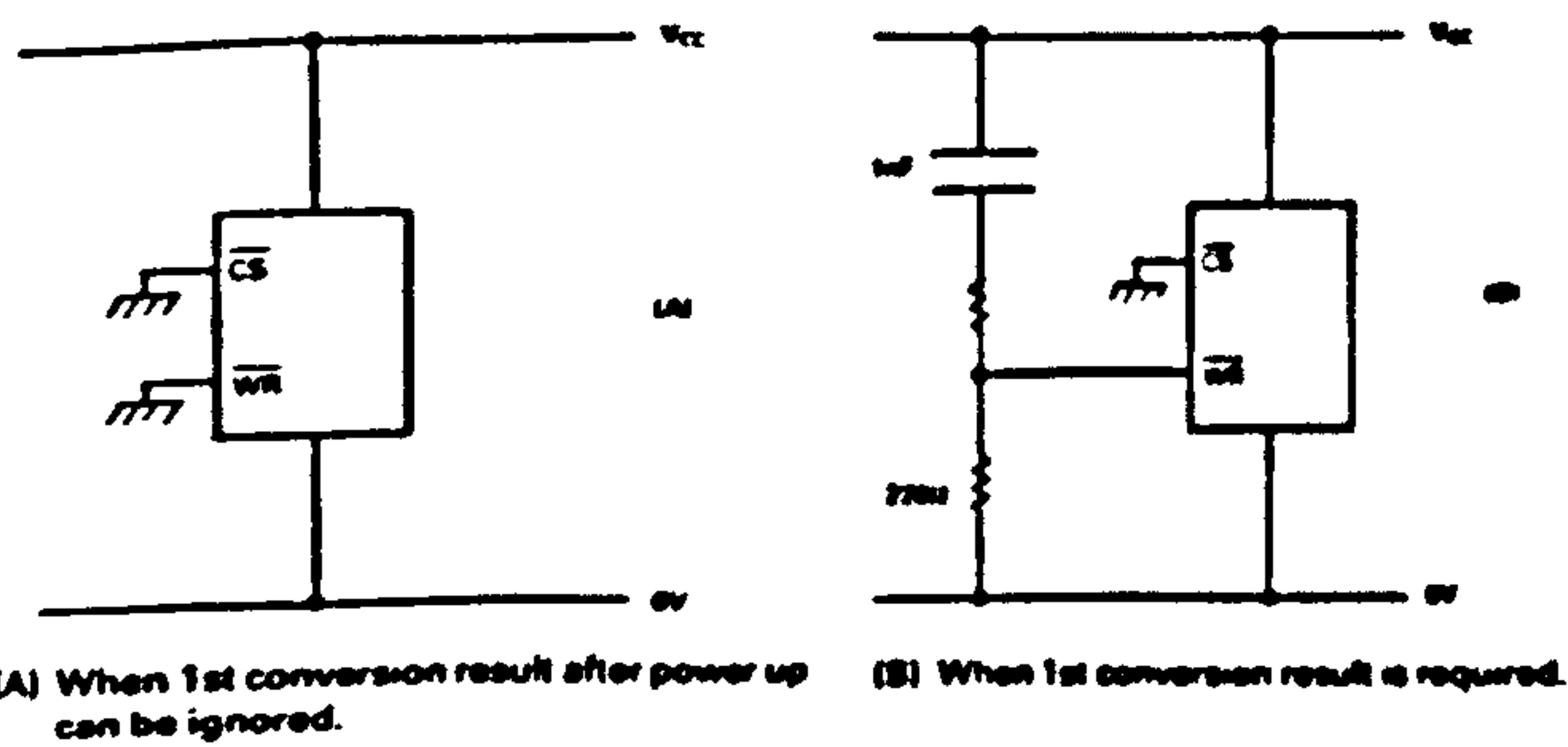


Figure 4 Circuit for continuous conversion



locked out during a conversion by removing the \overline{CS} signal. This will isolate the converter from the external signals around it.

The status output goes low at the end of a conversion indicating that new data is now available. Internal logic monitors the \overline{WR} input and if at the end of a conversion the \overline{WR} input is high the clock signal will be locked out of the converter leaving it set up (ie. the code 10000000 will appear on the input to the DAC) and waiting for its next convert (\overline{WR}) pulse.

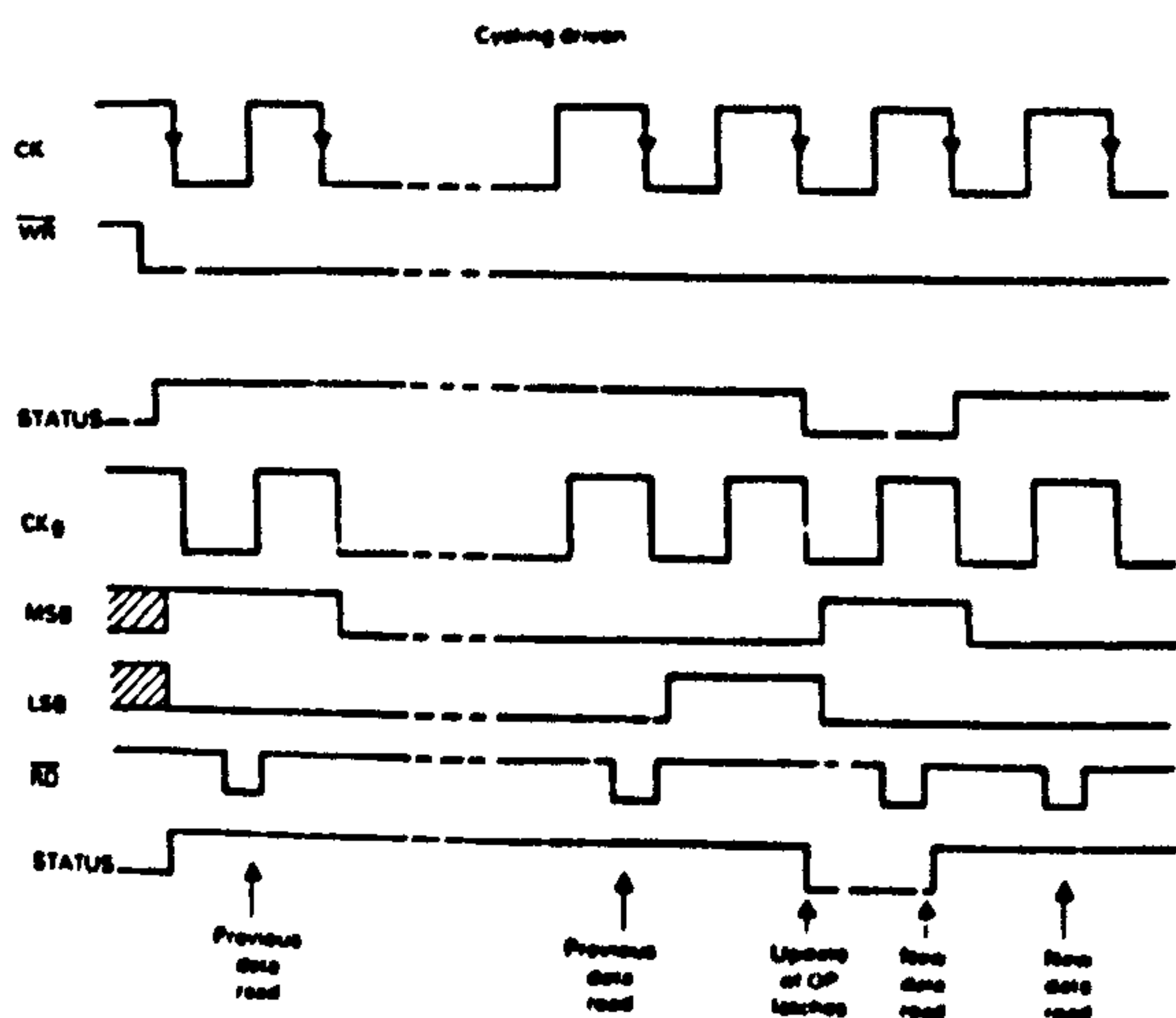
If the \overline{WR} input is low the clock signal will not be inhibited allowing the converter to proceed with another conversion. The double buffering on the 3-state data outputs give extra flexibility allowing the \overline{RD} input to operate completely asynchronously with respect to the status and always produce valid data. Note that the \overline{RD} input cannot be tied low as this will prevent the converter from updating at the end of a conversion.

Continuous conversion

The ZN439 can be made to cycle by simply tying the \overline{CS} and \overline{WR} inputs low. If, after a power up, the result of the first conversion can be ignored then no further external components are needed to operate the device in this mode. If however, the result of the first conversion is required an external R and C are needed to ensure a high to low transition on the \overline{WR} pin which will ensure correct operation immediately.

A timing diagram for the continuous conversion mode is shown in Figure 5.

Figure 5 Timing for continuous conversion

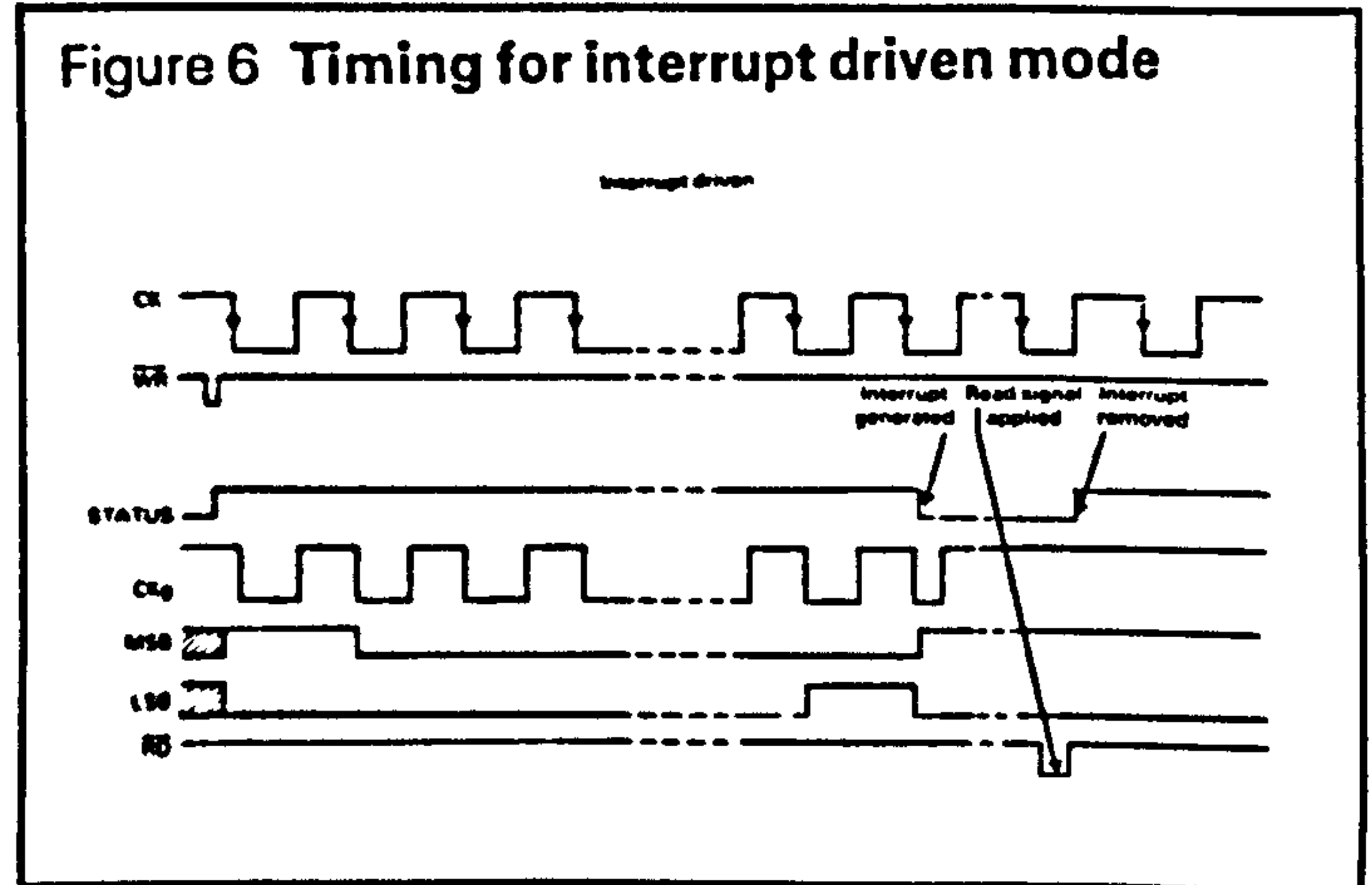


Interrupt driven

The ZN439 can also be used in an interrupt driven mode by using the status output. A \overline{WR} pulse initiates a conversion sending the status high. The high to low transition of the STATUS output, indicating the end of a conversion, can be used as an interrupt signal by the microprocessor ie. informing the microprocessor that a conversion has been completed. On receiving the interrupt the microprocessor sends out an \overline{RD} pulse to take in the new data. On the rising edge of the \overline{RD} pulse data is latched into the microprocessor and internal control logic forces the status output high hence removing the interrupt signal.

A timing diagram for the interrupt driven mode is shown in Figure 6.

Figure 6 Timing for interrupt driven mode

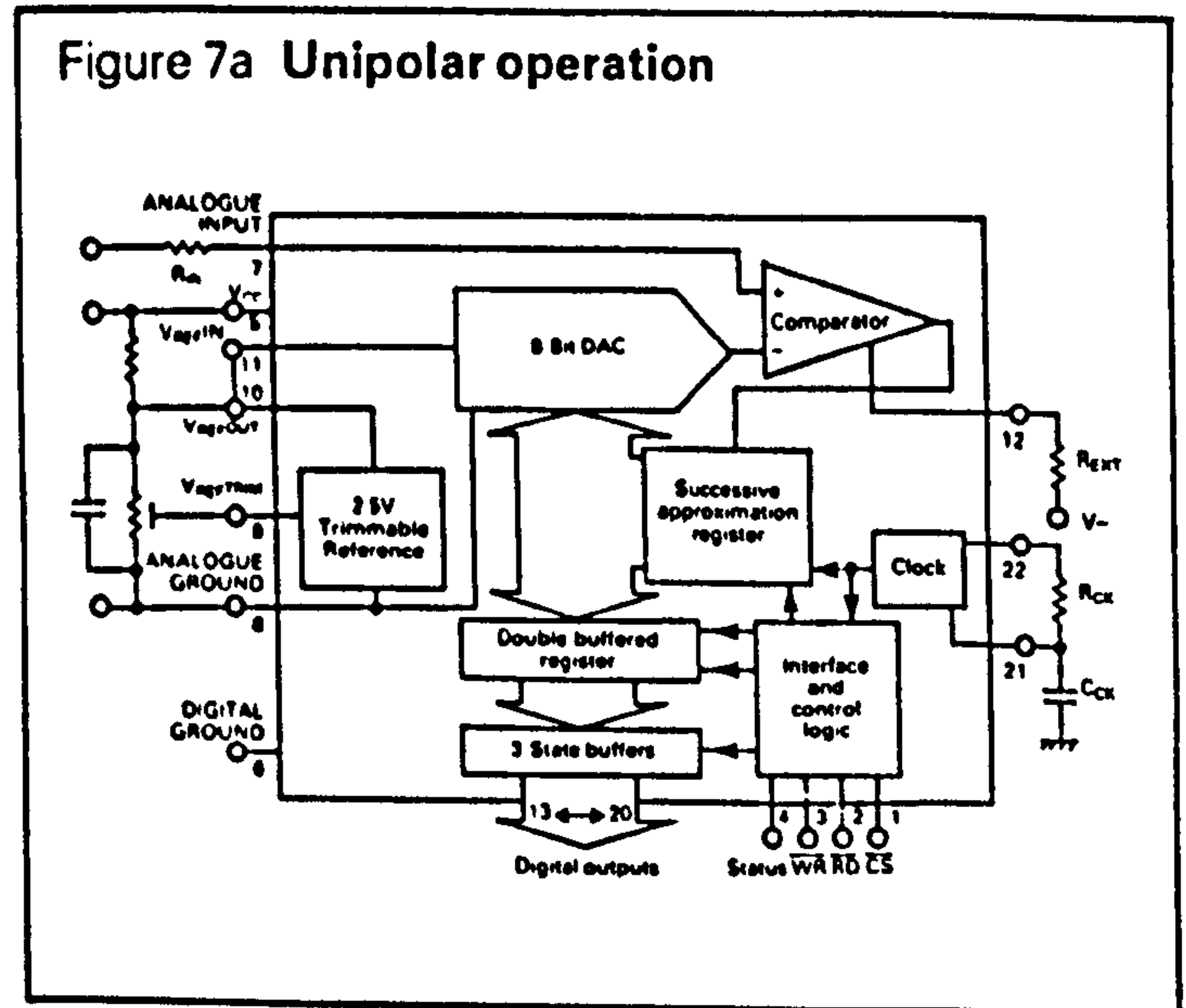


'Stand alone' operation

The ZN439 is equally suitable for stand alone applications containing an on-chip clock and a 2.5V trimmable bandgap reference.

A typical circuit for unipolar operation is shown in Figure 7a.

Figure 7a Unipolar operation



By tying the \overline{WR} and \overline{CS} inputs low the device can be made to cycle. Also if the status output is connected via an inverter to the \overline{RD} input the device can be updated at the end of each conversion and the output buffers enabled without the need for extra external control signals.

A timing diagram for stand alone operation is shown in Figure 8.

Figure 7b Circuit for updating 'stand alone' converter

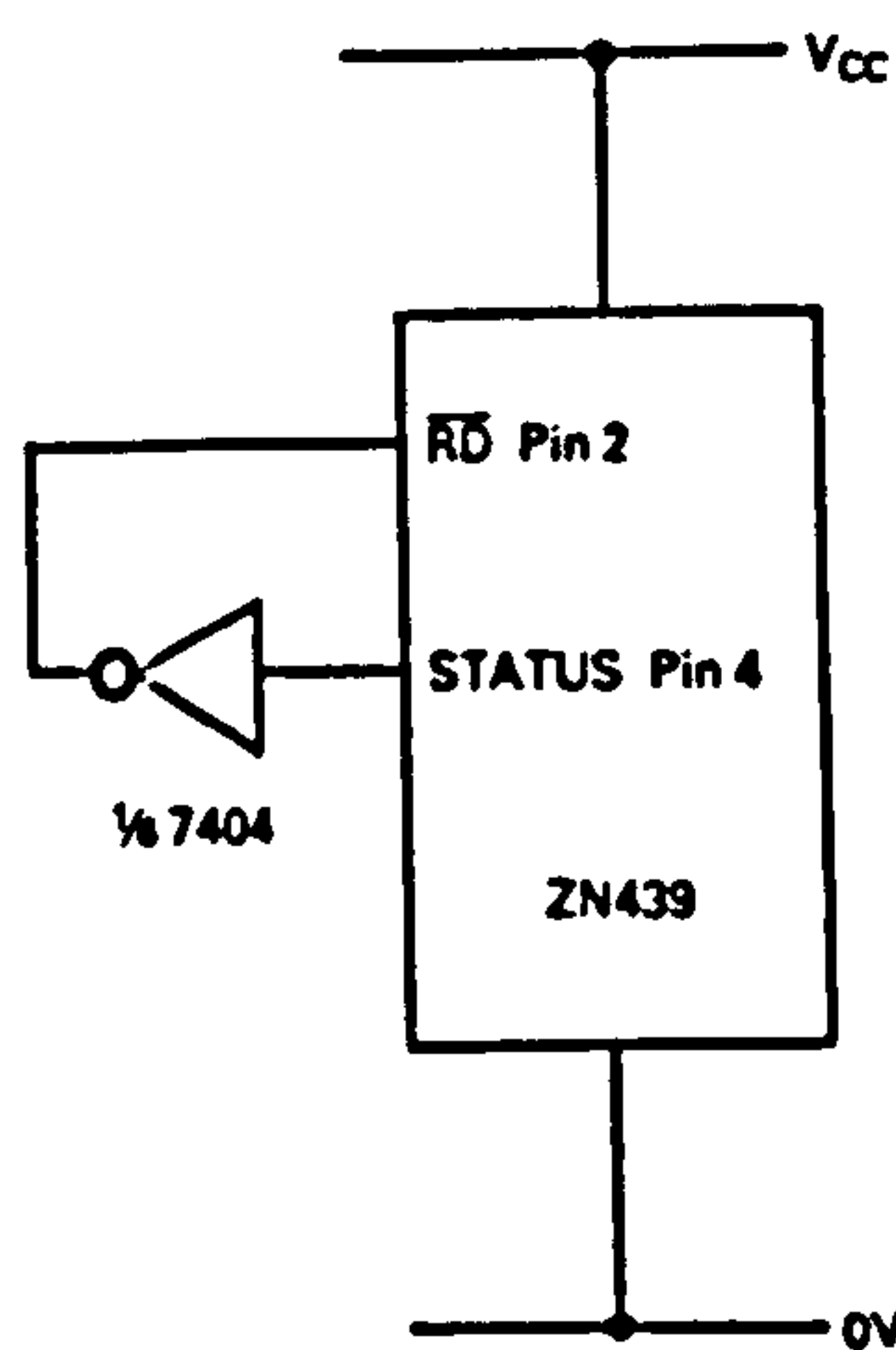


Figure 10 Output enable/disable delays

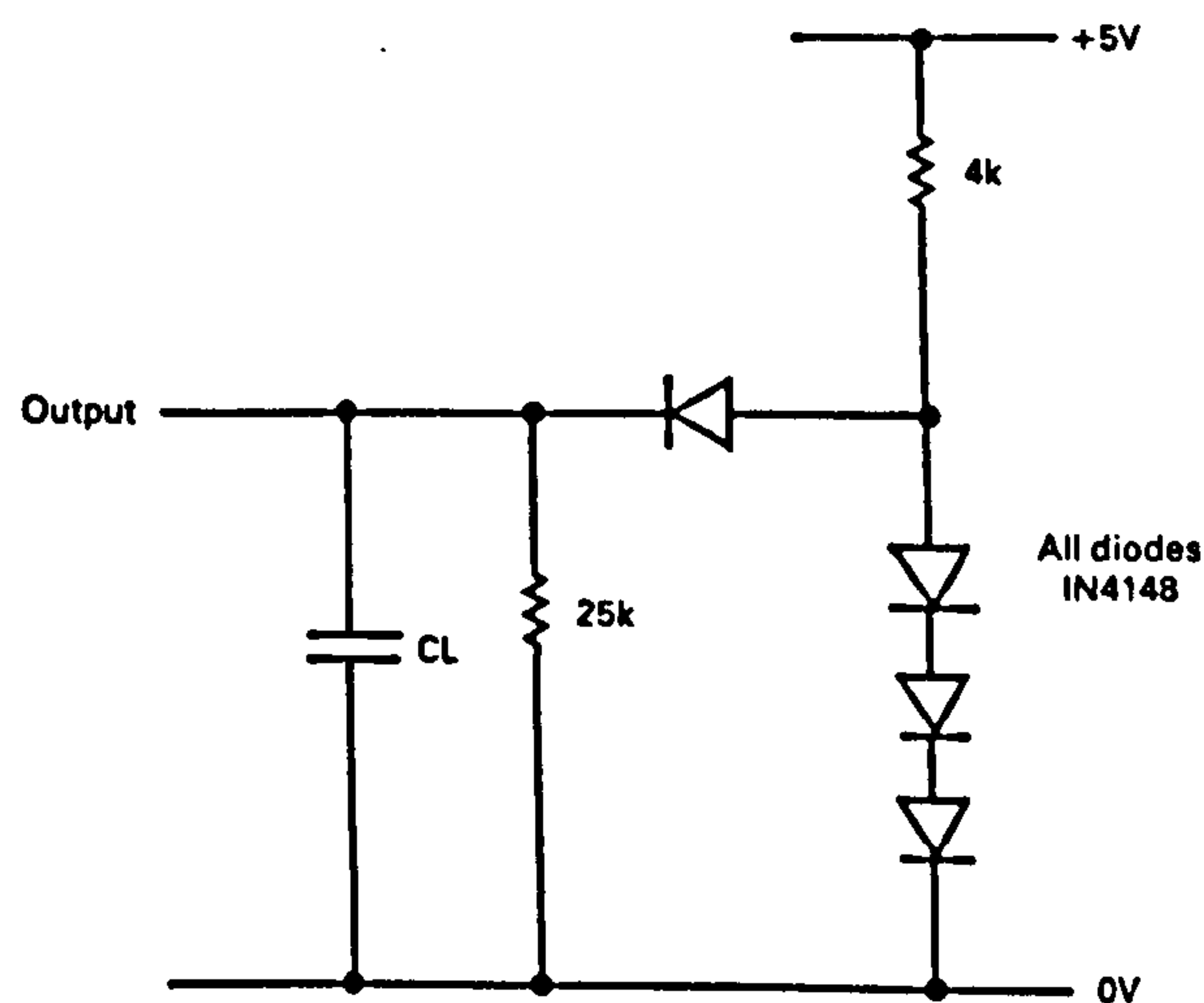
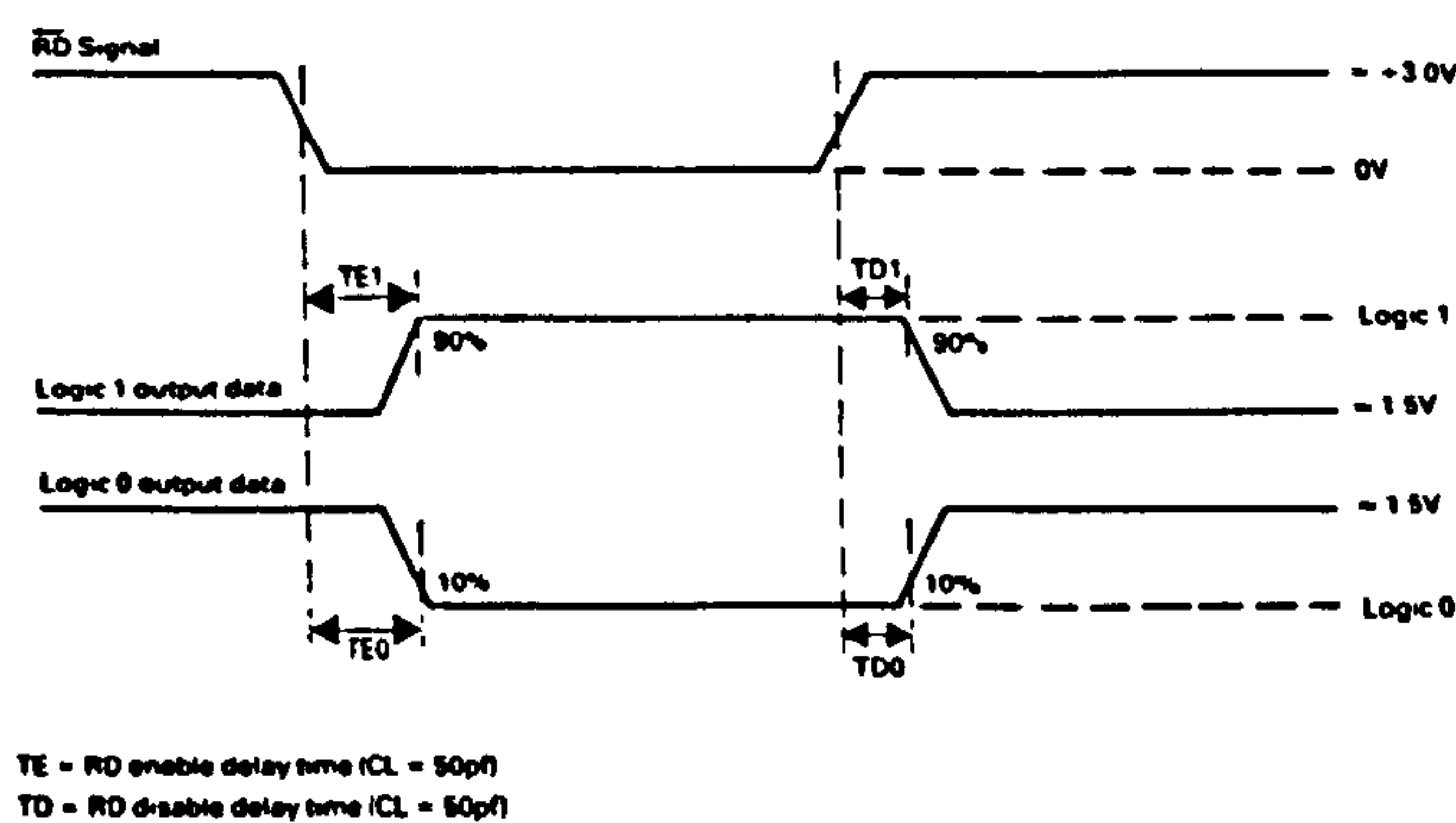
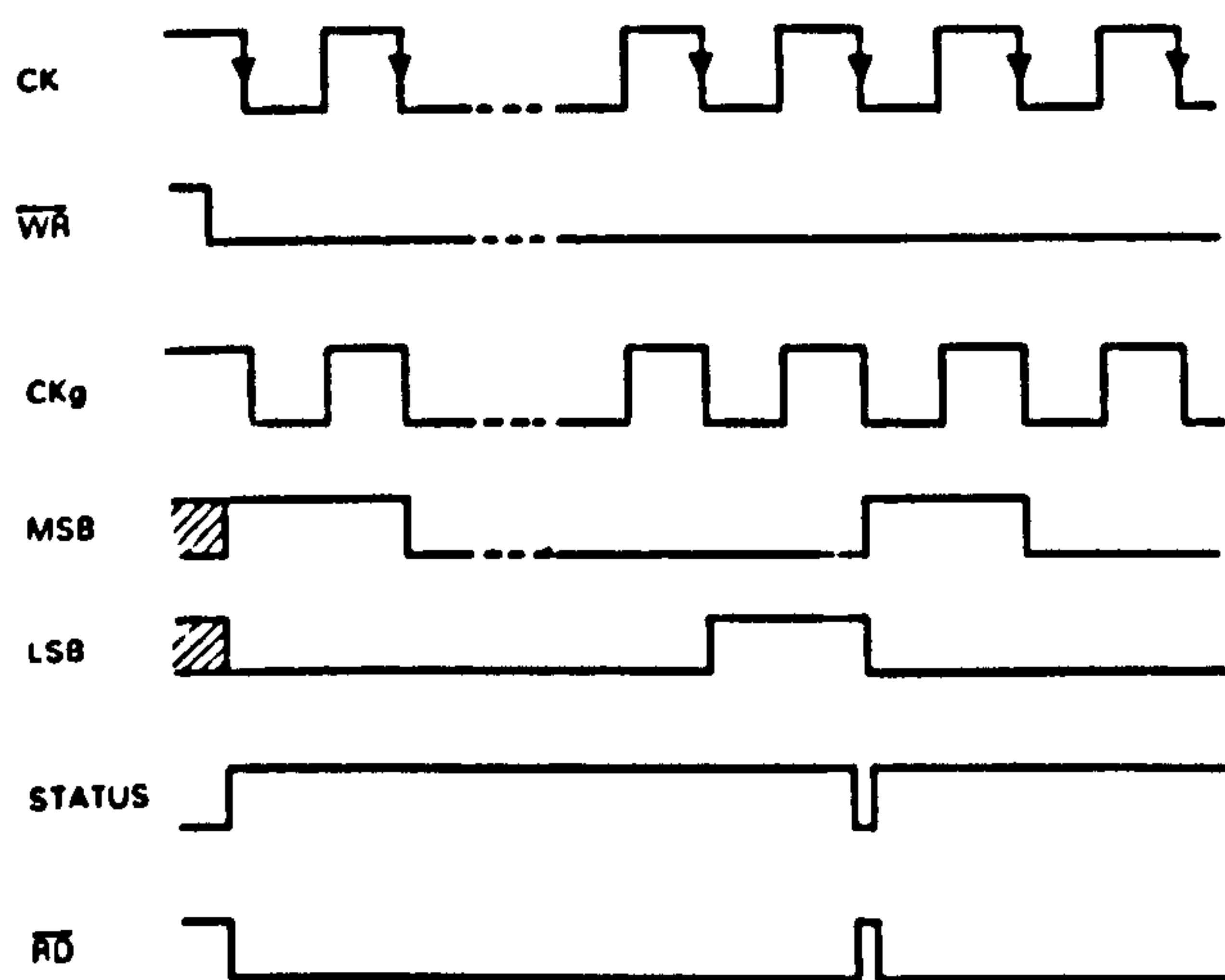


Figure 8 Timing for 'stand alone' operation



Data outputs

The data outputs are provided with 3-state buffers to allow connection to a common data bus. An equivalent circuit is shown in Figure 9. Whilst the RD input is high both output transistors are off and the device presents only a high impedance load to the bus. When RD is low the data outputs will assume the logic states present on the outputs of the double buffered register.

A test circuit and timing diagram for the output enable/disable delays are given in Figure 10.

The status output utilises the same active pull-up as the data outputs for CMOS/TTL compatibility.

Figure 9 Data outputs

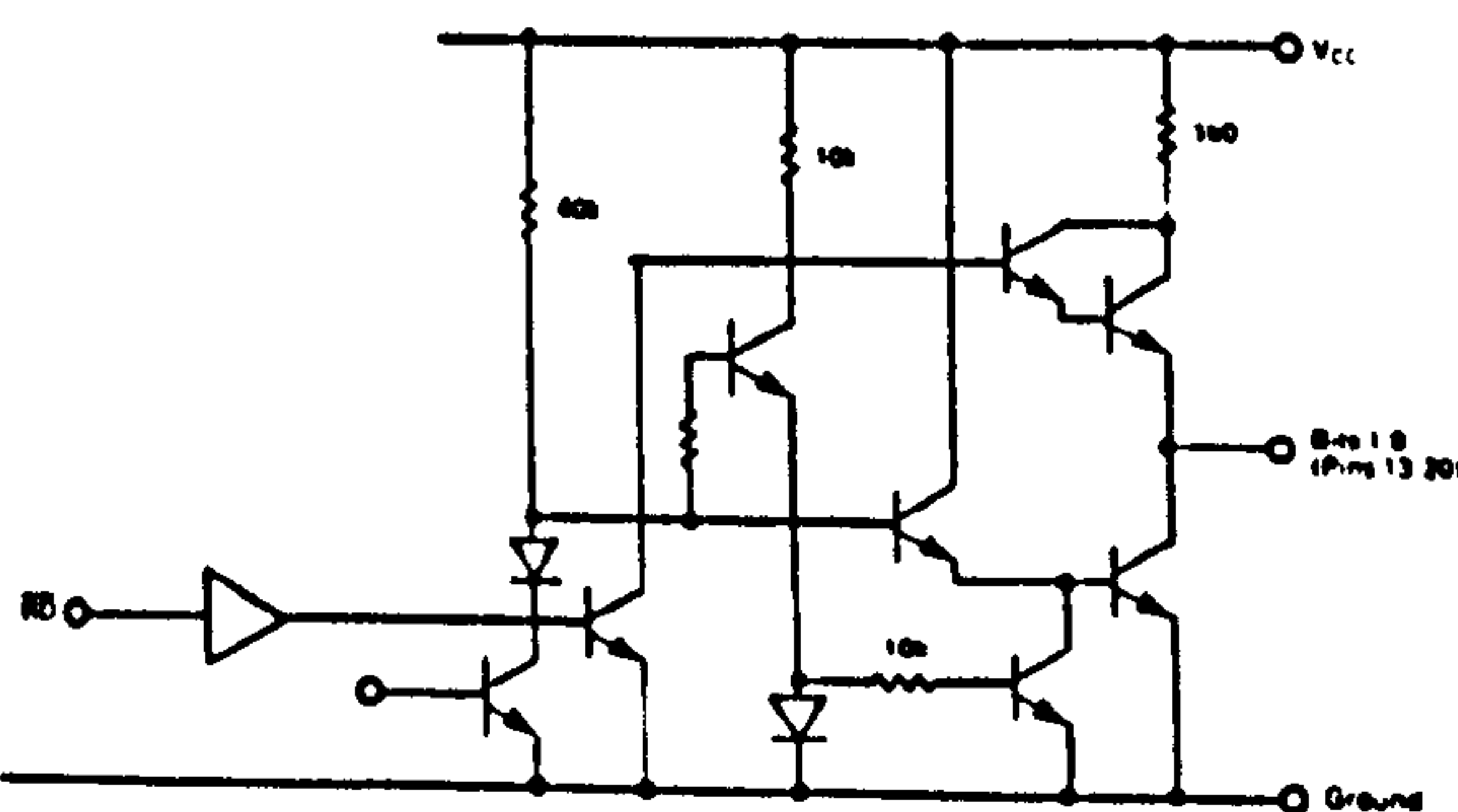
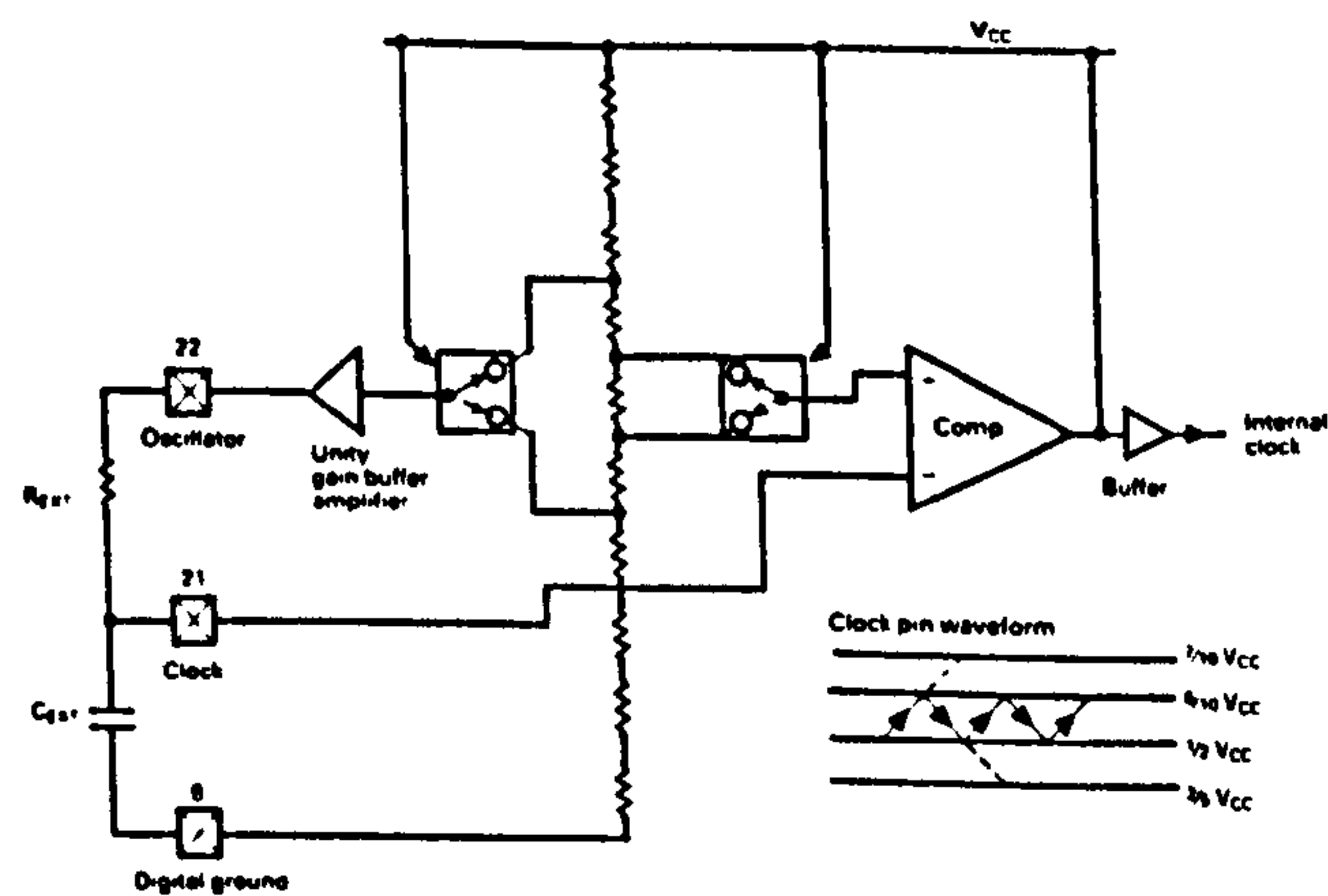


Figure 11 Clock oscillator circuit



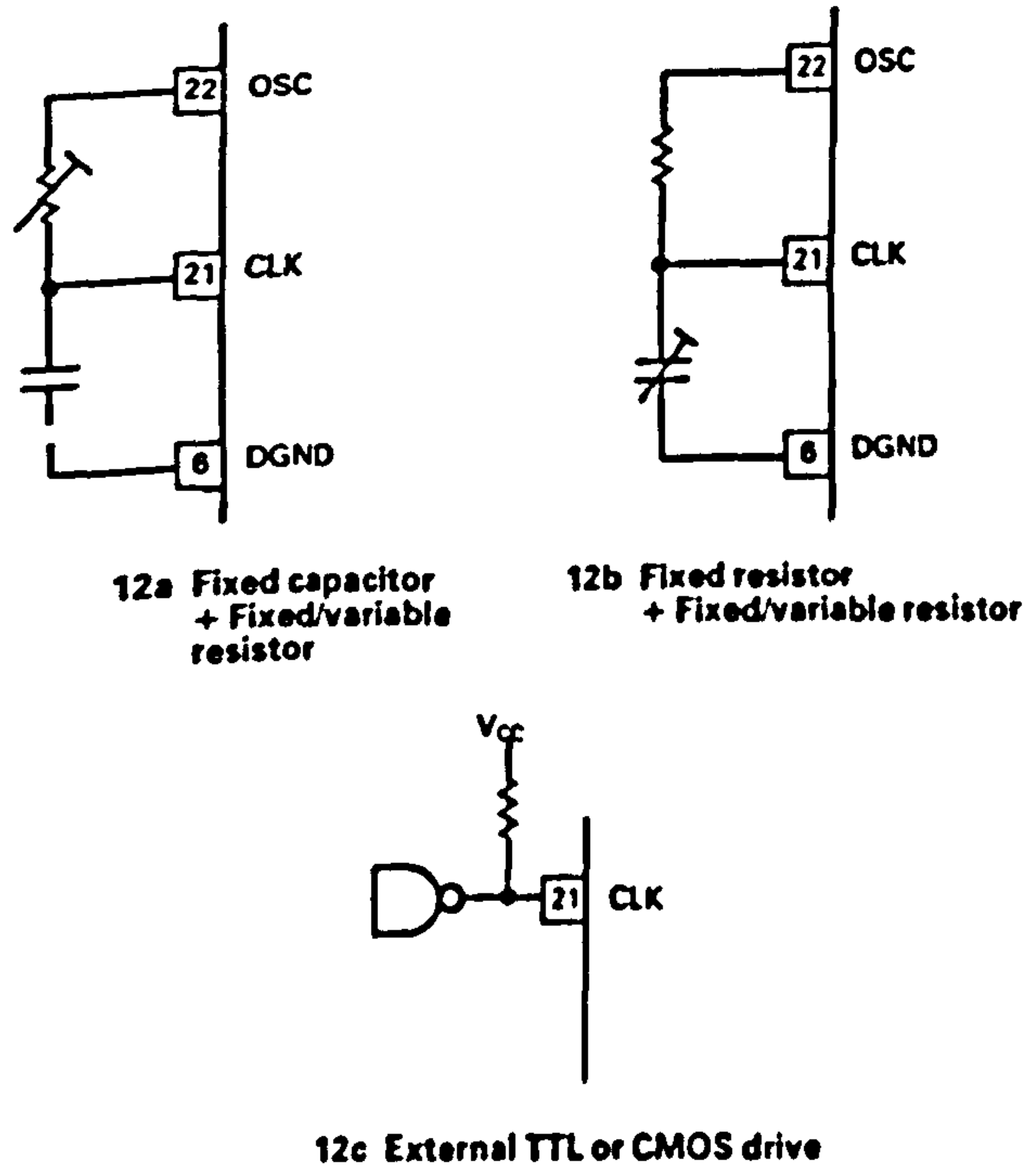
On-chip clock

The ZN439 on-chip clock oscillator operates with only two external components; a resistor connected between pin 21 and pin 22 and a capacitor between pin 21 and pin 6. The clock oscillator circuit and the external component connections are shown in Figure 11.

The oscillator frequency may be varied with the aid of a potentiometer or variable capacitor as shown in Figure 12a and Figure 12b. Alternatively it is possible to overdrive the oscillator input with an external clock signal from a TTL or CMOS gate as shown in Figure 12c.

A graph of oscillator frequency against capacitor and resistor values is given in Figure 13.

Figure 12 Clock circuit external components



The minimum current required to drive one ZN439 is nominally 1.5mA and will be supplied by an R_{REF} of 1k6 [(5 - 2.56)/1k6 = 1.5mA].

If the reference is required to drive more than one ZN439 then the reference current can be increased eg. an $R_{REF} = 470\Omega$ will supply a nominal reference current of $(5 - 2.56)/0.47 = 5.2mA$ and this may be used to drive up to four ZN439s from just one internal reference. This useful feature saves power and gives excellent gain tracking between the converters.

Alternatively with $R_{REF} = 470\Omega$, the internal reference can be used as the reference voltage for other external circuits and can source or sink up to 2mA.

(b) External reference

If required an external reference in the range +1.5 to +3.0 volts may be connected to $V_{REF IN}$. The slope resistance of such a reference source should be less than $\frac{2.5\Omega}{n}$, where n is the number of converters supplied.

Ratiometric operation

If the output from a transducer varies with its supply then an external reference for the ZN439 should be derived from the same supply. The external reference can vary from +1.5 to +3.0 volts. The ZN439 will operate if $V_{REF IN}$ is less than +1.5 volts but reduced overdrive to the comparator will increase its delay and so the conversion time will need to be increased.

Figure 13 Typical clock frequency vs R and C values

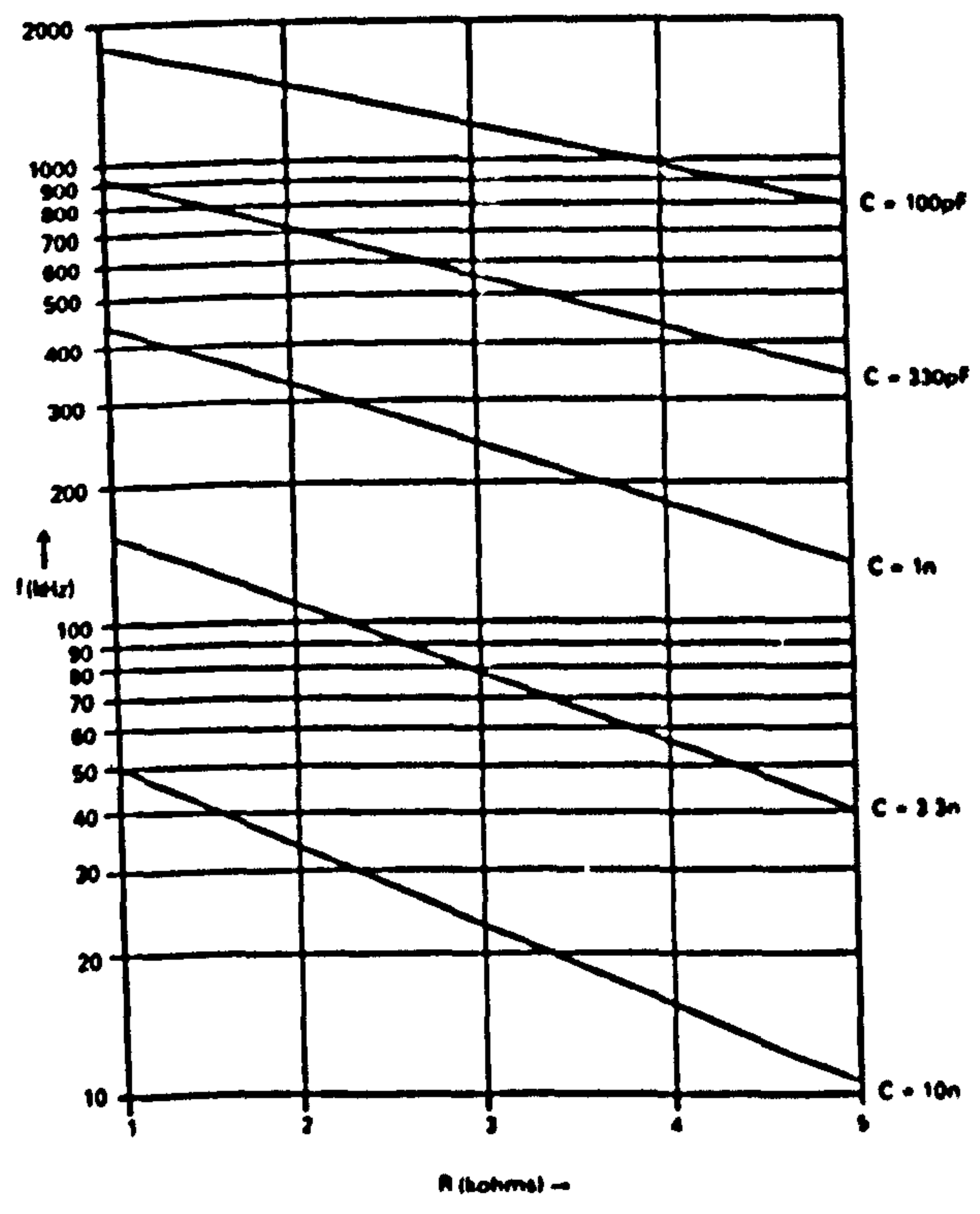
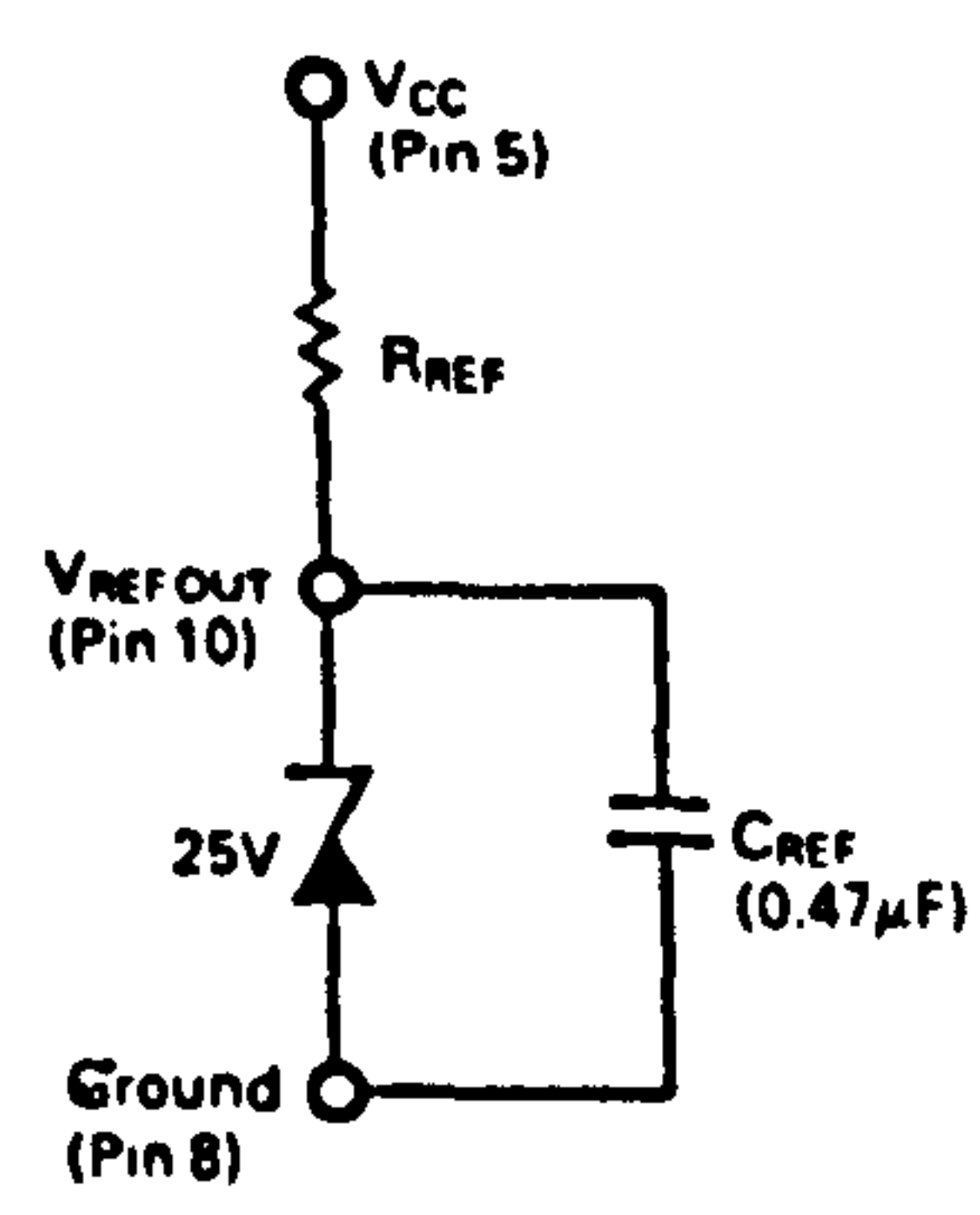


Figure 14 Internal voltage reference



Comparator

The ZN439 contains a fast comparator, the equivalent input circuit of which is shown in Figure 15. A negative supply voltage is required to supply the tail current of the comparator. However as this is only 25 to 150µA and need not be well stabilized it can be supplied by a simple diode pump circuit driven from the R_{CK} pin (Pin 22).

Analogue circuits

Reference

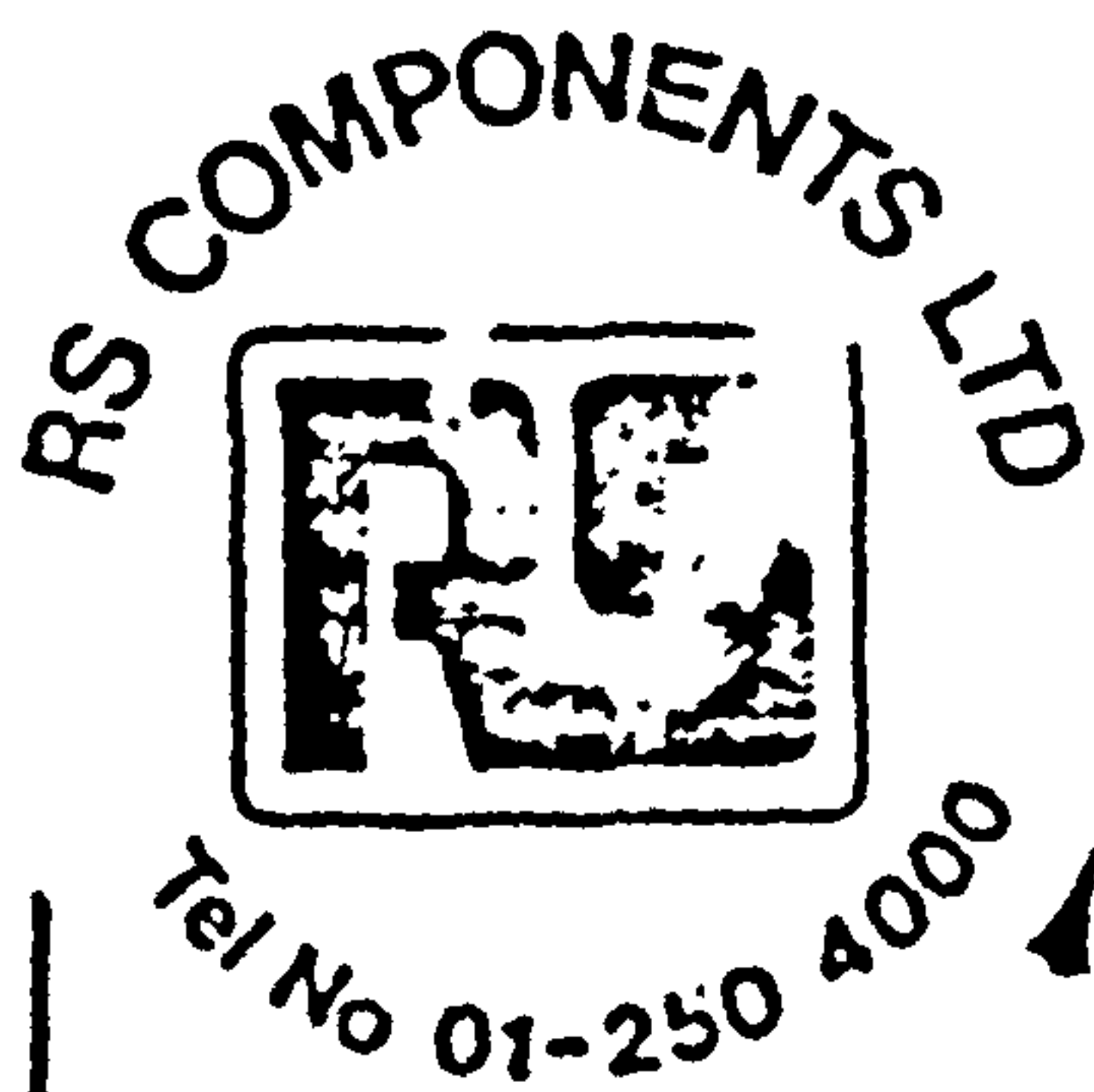
(a) Internal reference

The internal reference is an active bandgap circuit which is equivalent to a 2.5 Zener diode with a very low slope impedance (Figure 14). A resistor (R_{REF}) should be connected between V_{CC} and $V_{REF OUT}$, and a decoupling capacitor, C_{REF} ($0.47\mu F$), is required between $V_{REF OUT}$ and AGND. For internal reference operation $V_{REF OUT}$ is connected to $V_{REF IN}$.

633-694

APPENDIX 4

Shows data sheets for chart recorder recommended
to be used with pressure sensor system

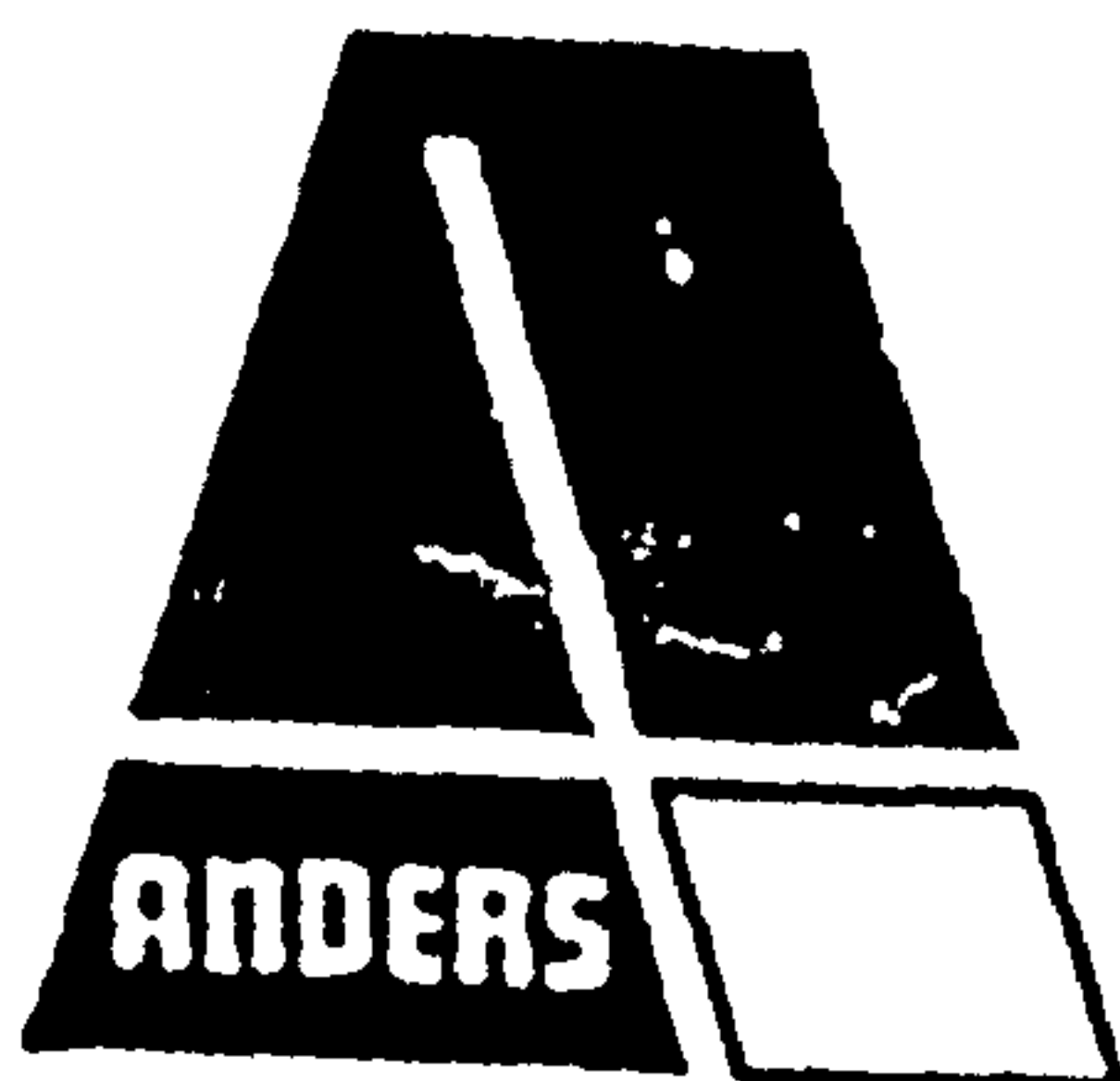


INSTRUCTION
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MINIATURE
CHART RECORDERS

"Instruments for Industry"



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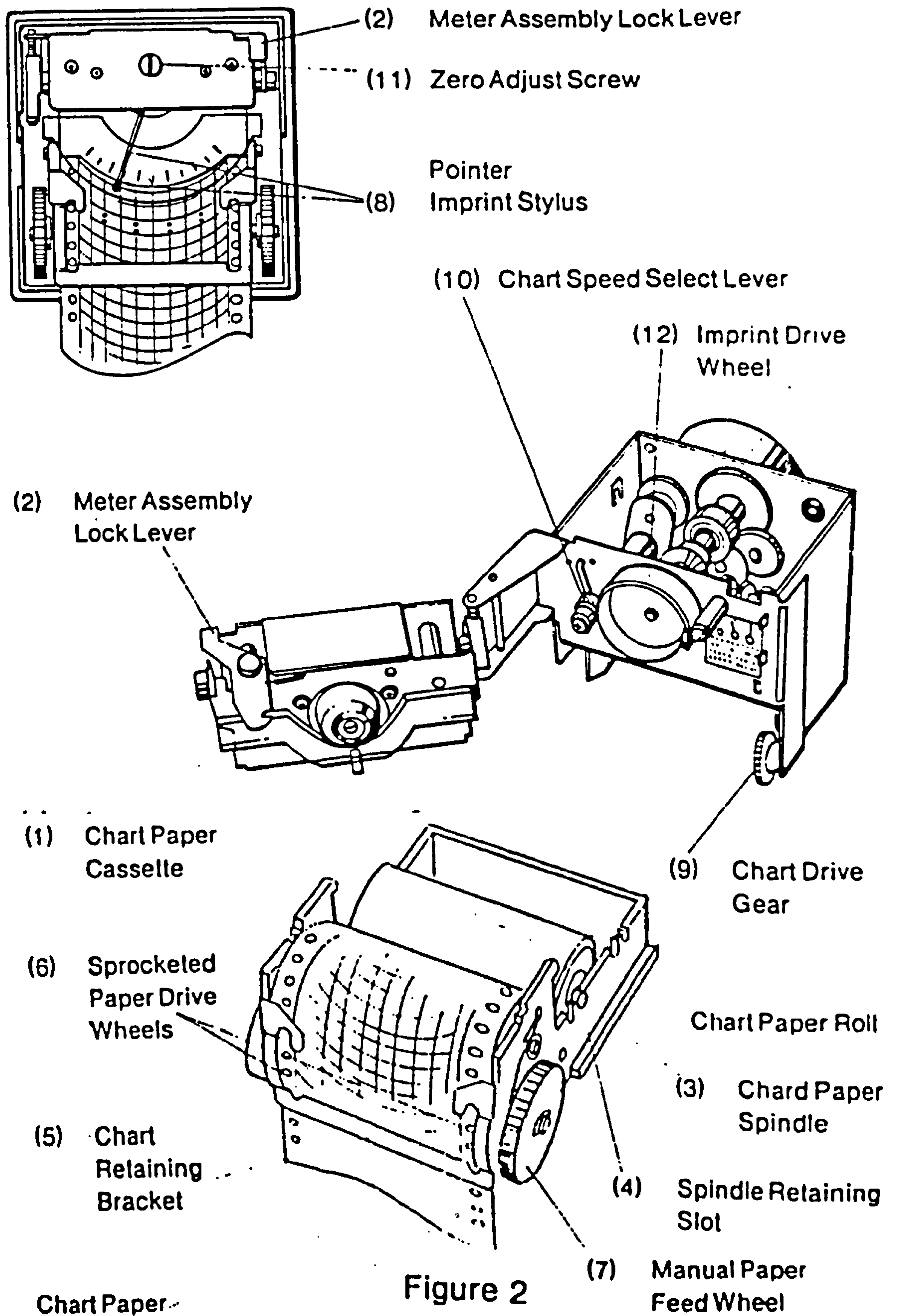
48-56 Bayham Place,
London NW1 0EU.

Telephone: 01-387 909

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SPECIFICATIONS

Chart Width	50mm
Scale Length	55mm arc
Recording System	Direct dot printing on pressure sensitive paper
Chart Paper	Width 2.5in (63.5mm), Length 60ft (18.3m)
Chart Speeds	
3 speed models	1/12/24 inch per hour (25/305/610 mm per hour)
single speed models	1 in/hr (25mm/hr)
Imprint Rate	60 dots per inch (2.36 per mm) at all speeds
Input/Scale Range	Consult unit labelling for details
Meter Scale Accuracy	$\pm 2\%$ of full scale (at $23^{\circ}\text{C} \pm 10^{\circ}\text{C}$)
Power Supply	240V $\pm 10\%$, 50Hz, 3.5VA standard, consult unit labelling for details
Isolation Voltage	500VAC between input terminal & chassis 1,500VAC between power supply terminal & chassis 2,000VAC between all terminals & housing case (except for case fixing screws)
Operating Temp.	-10°C to 50°C
Dimensions	Bezel $96 \times 96\text{mm}$, overall depth 162mm
Panel Cut-Out	$92 \times 92\text{mm}$ ($-0, +0.8\text{mm}$)



INSTRUCTIONS

A. Installation

1. Ensure that intended power supply and input are appropriate for the model designation as detailed on the rear label.
2. This recorder is designed to operate in the "tear-off" mode and should be mounted in a vertical panel with adequate space below the front cover to allow a free flow of chart paper.
3. Cut panel cutout $92 \times 92\text{mm}$ ($-0, +0.8\text{mm}$)
4. Place recorder into cutout and retain with rear mounting clamp.
5. Connect power supply and input wires to the rear screw terminal connection block. Observe polarity of dc inputs. No connection should be made to the middle terminals of basic models.

Caution: Ensure that the power supply and input are both switched off and isolated prior to making connections or changes to the terminal block.

B. Chart Paper Loading (see figure 2)

1. Remove front bezel by simultaneously pressing the retaining catches on each side.
2. To gain access to the chart paper cassette (1). First, unlock the meter assembly by moving the locking lever (2) to the left and hinge outwards. Remove cassette by gripping firmly and pulling forward.
3. To load chart paper. First, fit spindle (3) into new roll of chart paper. Clip roll into spindle retaining slots (4) on the cassette with the paper unrolling from the bottom. With the chart retaining bracket (5) lifted, feed the paper onto the sprocketed paper driving wheels (6).

APPENDIX 5

Shows Fisher Table to evaluate χ^2

TABLE II χ^2

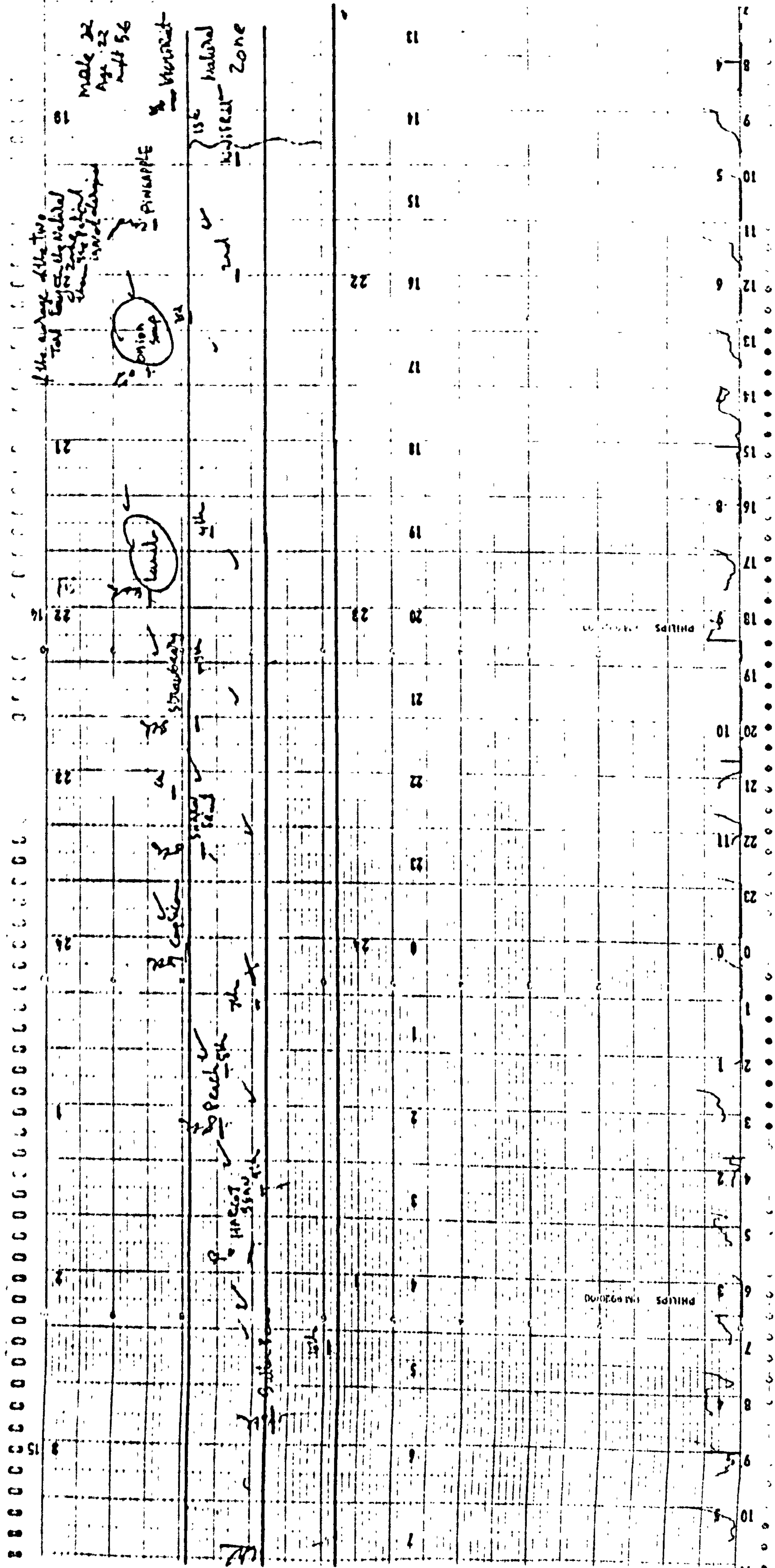
Probability of a larger value of χ^2

D.F.	.99	.98	.95	.90	.80	.70	.50	.30	.20	.10	.05	.02	.01	.001
1	.0157	.0423	.00993	.0155	.0642	.148	.455	1.074	1.612	2.706	3.841	5.412	6.635	10.827
2	.0201	.0404	.0103	.0111	.046	.713	1.340	2.408	3.219	4.605	5.991	7.879	9.210	13.815
3	.115	.185	.0352	.0594	1.005	1.424	2.366	3.665	4.612	6.251	7.815	9.843	11.345	16.266
4	.297	.479	.0711	1.064	1.619	2.195	3.357	4.878	5.983	7.779	9.488	11.145	13.277	19.405
5	.544	.752	1.145	1.610	2.343	3.010	4.351	6.064	7.289	9.236	11.070	13.155	15.086	20.517
6	.872	1.134	1.635	2.204	3.070	3.828	5.345	7.231	8.558	10.645	12.592	14.453	16.812	22.457
7	1.239	1.664	2.167	2.833	3.822	4.671	6.340	8.383	9.863	12.017	14.067	16.022	18.475	24.322
8	1.646	2.032	2.733	3.490	4.594	5.527	7.344	9.524	11.030	13.362	15.467	17.168	19.020	26.125
9	2.088	2.532	3.325	4.168	5.380	6.393	8.343	10.656	12.242	14.684	16.919	18.679	21.026	27.877
10	2.558	3.059	3.940	4.865	6.179	7.267	9.312	11.781	13.442	15.987	18.307	20.483	23.210	29.588
11	3.053	3.609	4.575	5.578	6.980	8.148	10.311	12.809	14.631	17.275	19.675	22.161	24.725	31.204
12	3.571	4.178	5.226	6.304	7.807	9.034	11.340	14.011	15.812	18.549	21.026	23.210	26.217	32.909
13	4.107	4.765	5.892	7.042	8.634	9.926	12.340	15.110	16.985	19.412	22.362	24.472	27.688	34.678
14	4.660	5.368	6.571	7.790	9.467	10.821	13.339	16.222	18.151	20.264	23.685	25.790	29.141	36.123
15	5.229	5.983	7.261	8.547	10.307	11.721	14.339	17.372	19.313	21.064	24.786	27.033	30.578	37.697
16	5.812	6.614	7.962	9.312	11.152	12.624	15.338	18.418	20.465	22.842	26.190	28.289	32.000	39.252
17	6.408	7.255	8.672	10.085	12.002	13.531	16.338	19.511	21.615	24.769	27.587	30.191	33.409	40.790
18	7.015	7.906	9.390	10.865	12.857	14.440	17.338	20.601	22.790	25.980	28.869	32.301	34.805	42.312
19	7.633	8.567	10.117	11.651	13.716	15.352	18.338	21.680	23.940	27.204	30.144	33.597	36.191	43.820
20	8.260	9.237	10.851	12.443	14.578	16.266	19.337	22.775	25.018	28.412	31.410	35.020	37.566	45.315
21	8.897	9.915	11.591	13.210	15.445	17.182	20.337	23.858	26.171	29.615	32.671	36.191	38.932	46.797
22	9.542	10.600	12.338	14.041	16.314	18.101	21.337	24.939	27.301	30.813	33.924	37.569	40.280	48.268
23	10.196	11.293	13.091	14.848	17.187	19.021	22.337	26.018	28.420	32.047	35.172	38.932	41.638	49.728
24	10.856	11.992	13.848	15.659	18.062	19.943	23.337	27.046	29.563	33.196	36.416	40.270	42.989	51.179
25	11.524	12.697	14.611	16.473	18.940	20.867	24.337	28.172	30.705	34.382	37.652	41.660	44.311	52.620
26	12.198	13.409	15.379	17.292	19.820	21.792	25.336	29.240	31.795	35.863	38.885	42.850	45.642	54.052
27	12.879	14.125	16.151	18.114	20.703	22.719	26.336	30.319	32.912	36.741	40.113	44.140	46.963	55.470
28	13.565	14.847	16.928	18.939	21.588	23.617	27.336	31.391	34.027	37.916	41.337	45.419	48.278	56.803
29	14.256	15.574	17.708	19.768	22.475	24.577	28.336	32.461	35.139	39.087	42.557	46.693	49.588	58.302
30	14.953	16.306	18.493	20.599	23.364	25.508	29.336	33.530	36.250	40.256	43.773	47.962	50.892	59.703

† Reprinted from Table IV of R. A. Fisher and Frank Yates, "Statistical Tables for Biological, Agricultural and Medical Research," Oliver & Boyd, Ltd., Edinburgh and London, 1953, by permission of the authors and publishers.

APPENDIX 6

Shows a photocopy of the results obtained from the clinic to verify the validity of the muscle strength system



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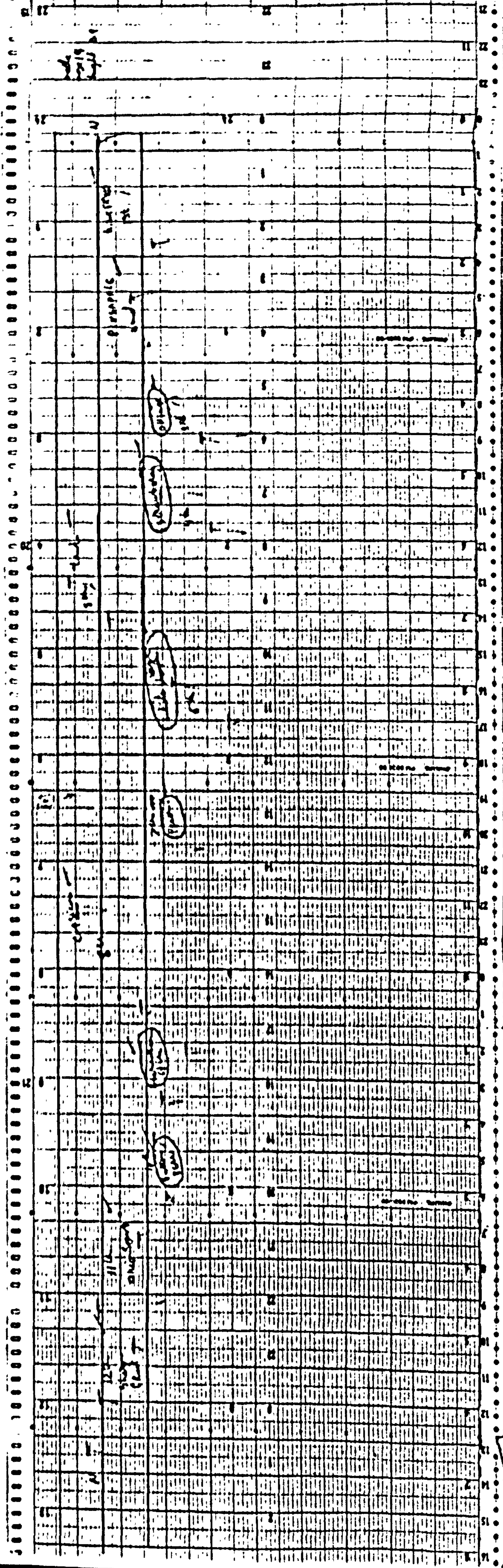
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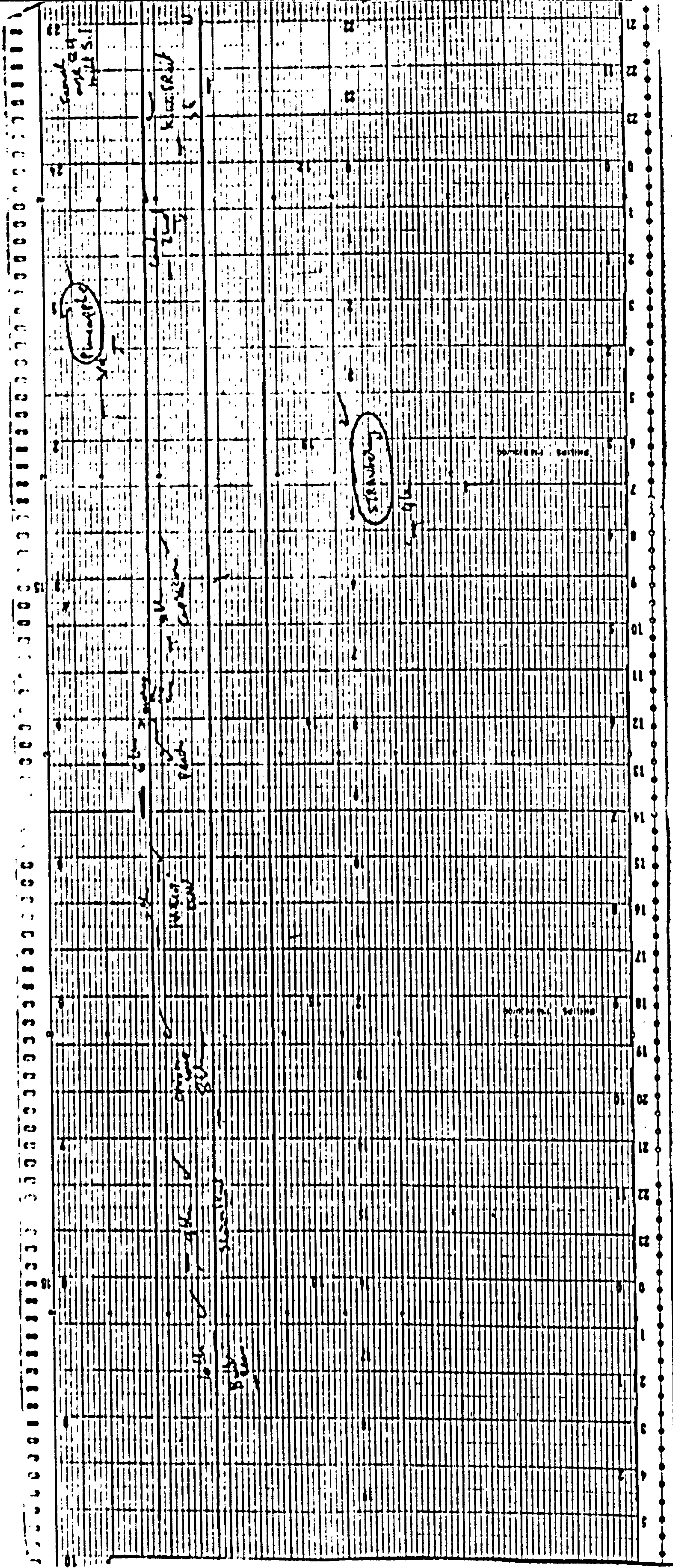
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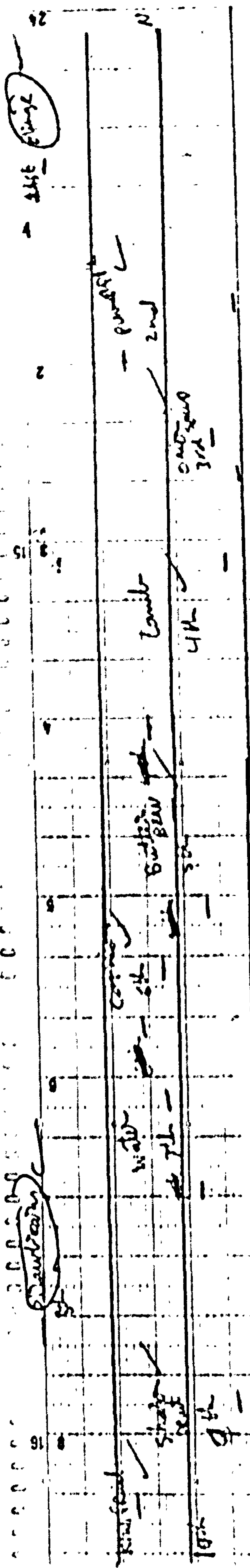
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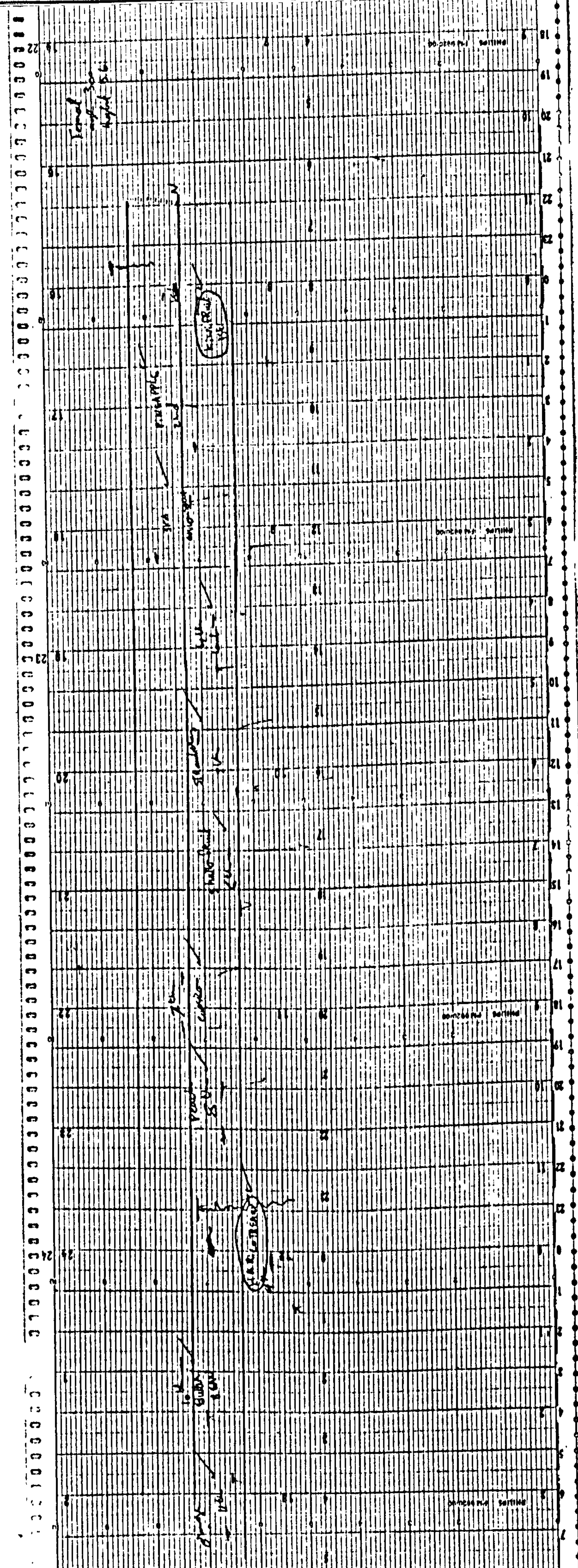
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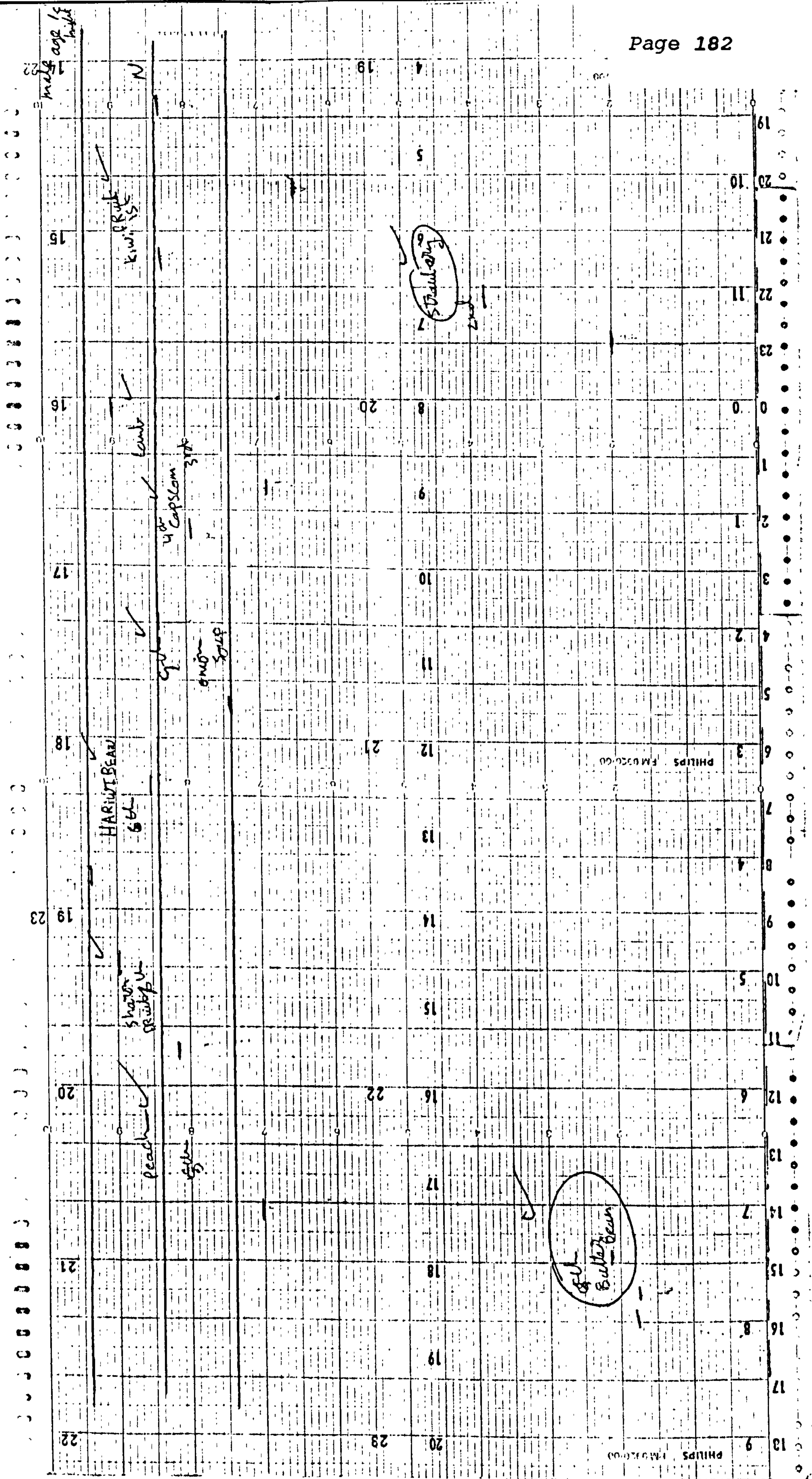
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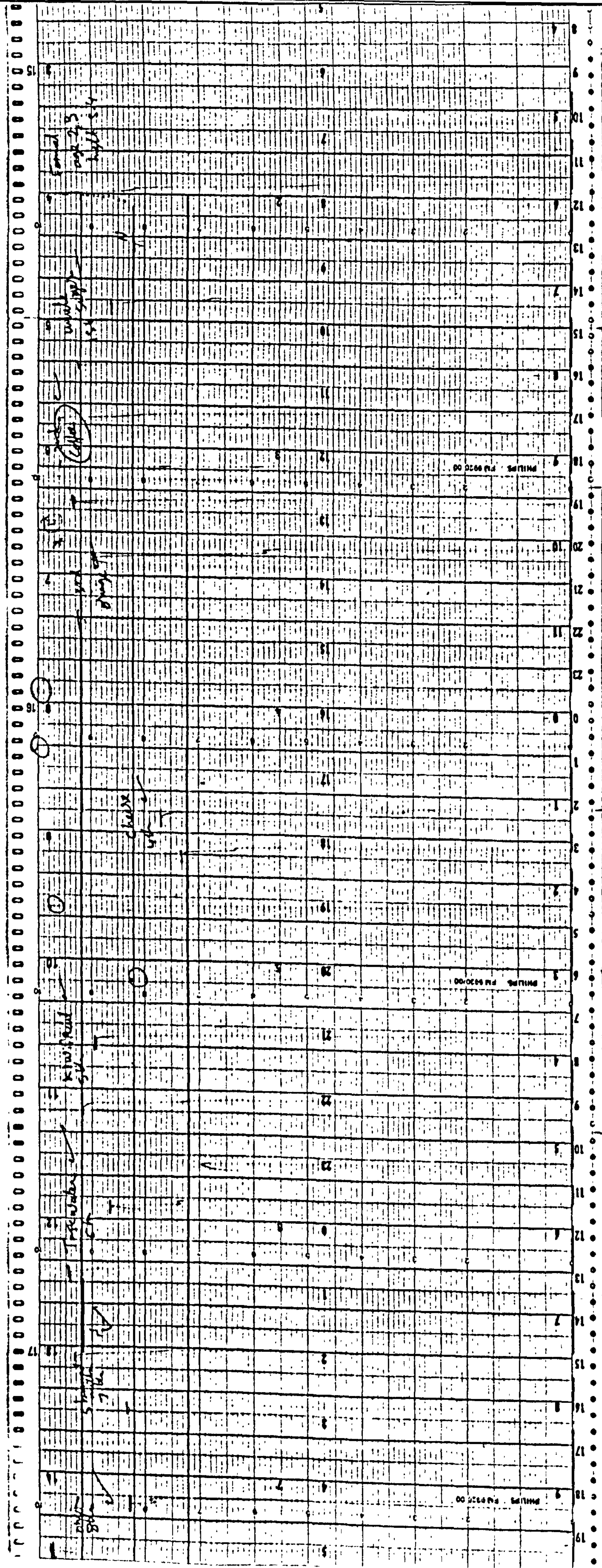
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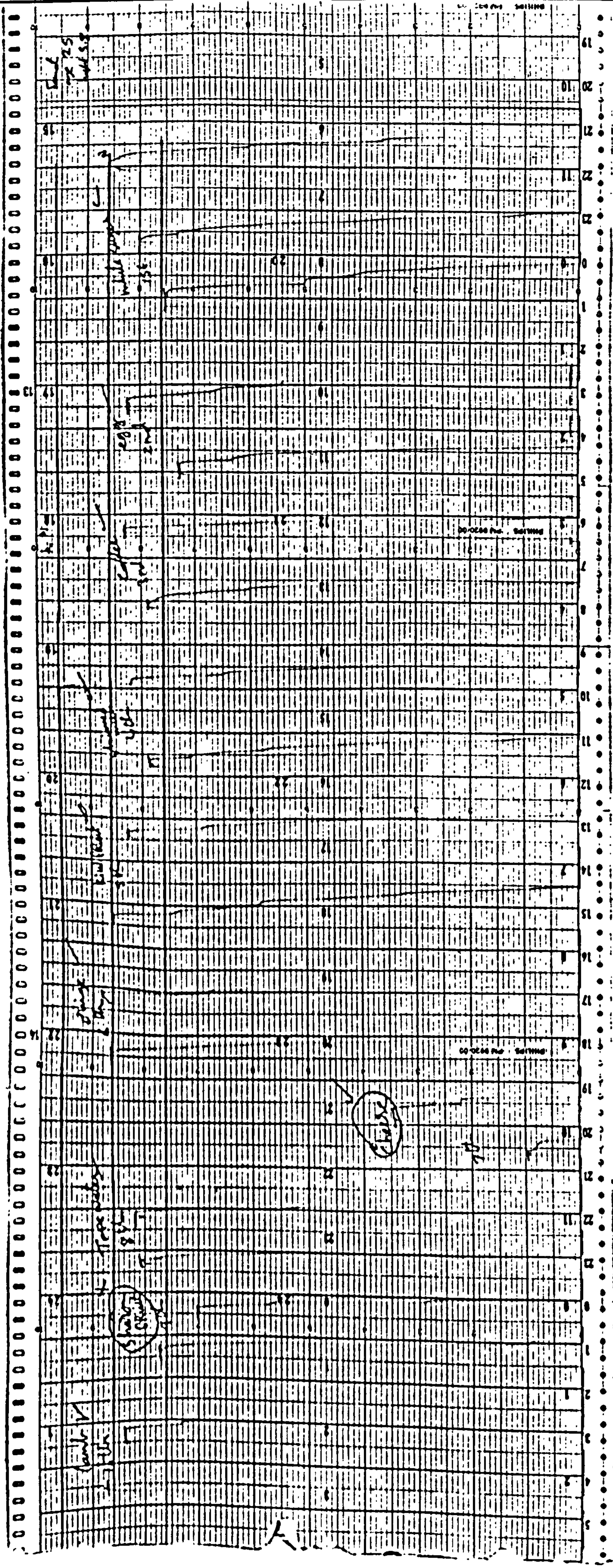
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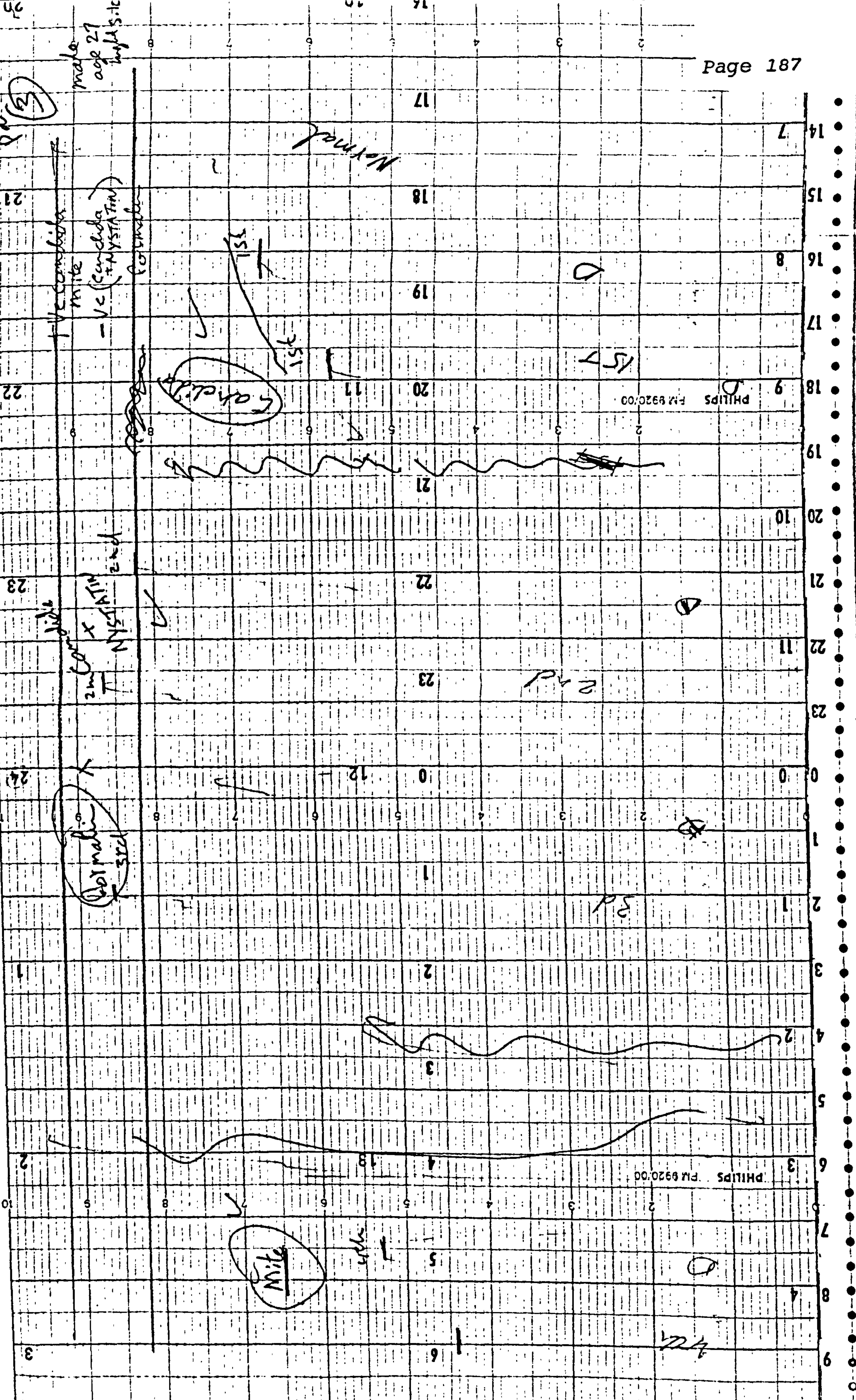
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