A REMOTE RADIO TRANSMISSION SYSTEM TO RECORD THE PHYSIOLOGICAL PHENOMENA OF AN EQUINE ATHLETE

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Declaration

I declare that the contents of this thesis represents my own work and that the opinions expressed are my own. It has not been submitted before any examination at this or any other institute.

W.T. Myburgh

This book is dedicated to my wife, Miranda, for her love and support.

TRIBUTE

I would like to pay tribute to the following people and institutions.

The Cape Technicon and especially Mr. P Kleinhans and Mr D de Beer for giving me the opportunity to do this research project.

Mr B Clark from Protea Electromedical for assistance and information rendered.

Mr A Bosch from UCT for information given.

Temperature Control & Co. for assistance.

SYNOPSIS

The call for the system design in this book came from a field that grew to be a part of millions of lives in this country. It is a sport which has developed to have a major infrastructure, with large sums of money involved. In fact, the money involved has made it one of the largest tax earners country wide. Due to its high development, competition has become furious and breeders will do their utmost to produce a competitor which would have the slightest edge on the next one.

As most people would know by now, the discussion is about the Horse Racing Industry. During the years, owners have relied on various exercising programs and breeding of proven winners to produce new ones. To give the animal the necessary training and simply run it on experience is no longer sufficient. A more scientific approach has become necessary. There exists a need for a system whereby one could monitor certain physiological aspects of the animal. This would not only allow the physical condition of each horse to be monitored, but also allow a more effective and specialized exercise program for each individual animal to be developed, thereby not only improving its ability, but saving on time as well.

Tests that were considered included ECG, temperature, and speed measurements. Existing equipment performing the first two tests require the animal to be stationary. This

defeats the object of the exercise, as information should be relevant to the animal when under strain.

During test periods, the ideal situation would be to allow the horse to perform its exercise routine around the track without any interference. This could best be done by monitoring all the necessary data via a radio link and having most of the analyzing apparatus in a small and light as possible package on the animal itself.

SINOPSIS

Die vraag vir die stelsel ontwerp in hierdie boek kom van 'n area wat in so 'n mate ontwikkel het, dat dit deel geword het van die daaglikse bestaan van miljoene mense in Suid - Afrika. Dit is 'n sport soort wat ontwikkel het tot 'n reuse infrastruktuur met groot somme geld op die spel. Die hoeveelheid geld betrokke het veroorsaak dat die bedryf gegroei tot een van die grootste bronne van belasting landwyd. A.g.v. die hoë mate van ontwikkeling, het kompetisie so toegeneem dat telers hulle absolute beste sal lewer om 'n deelnemer te produseer wat die geringste ligaamlike voorsprong op sy mede - deelnemers sal hê.

Hier word natuurlik verwys na die wedren bedryf. In die verlede, het eienaars staat gemaak op verskillende oefen programme en die teel met beproefde wenners om nuwe wenners te produseer. Met die verloop van tyd, is dit egter ondervind dat om die perd die nodige oefening te gee en te laat hardloop slegs op grond van ondervinding, onvoldoende is. 'n Behoefte het ontstaan vir 'n meer wetenskaplike benadering, verkieslik 'n stelsel wat sekere fisiologiese eienskappe van die dier kan monitor. So 'n stelsel sal nie net die afrigters in staat stel om die ligaamlike toestand van die perd te monitor nie, maar ook om 'n meer effektiewe en gespesialiseerde oefenprogram vir elke individuele dier uit te werk. Dit sal die perd se vermoë verbeter en terselfdertyd ook tyd bespaar.

Toetse waaraan gedink is, sluit in EKG, Temperatuur en Spoed meting. Bestaande apparaat wat eersgenoemde twee toetse uitvoer, vereis dat die perd in 'n statiese posisie verkeer wat die metings ongeldig maak. Daarom is die toetse meestal uitgevoer gedurende die behandeling van siek diere.

Die ideale situasie gedurende toets periodes, sal wees om die perd toe te laat om sy normale oefenprogram sonder hindernis rondom die baan te voltooi. Navorsing het getoon dat die beste manier om dit te bereik is om al die nodige analiseer apparaat in 'n klein en ligte kabinet op die perd self te installeer. Alle nodige data word dan via 'n radio verbinding na 'n basis - stasie gestuur waar dit op 'n deurlopende basis gemonitor word.

INTRODUCTION

In the early years of the Horse Racing Industry, trainers relied on experience to train the animals. Although this method was found sufficient to keep the horses relatively competitive , during the last 10 years or so, competition has become so furious that a pressing need was felt to discover new methods of training which would give the trainer an edge over the next competitor. Various methods were thought of and the system design proposed in this book facilitates for monitoring certain physiological aspects of the race horse during exercise.

Tests that are included is ECG & Temperature measurements. The system is completely mobile and all analysis is done on the animal while it is in motion around the track. This information is then sent via a radio link to the base station on a continuous basis, where further processing and analysis are done.

The complete system consists of the following:

1 Temperature transmit channel with a bandwidth of 560 Hz.

2 ECG transmit channel with a bandwidth of 55Hz.

3 Radio transceiver with a bandwidth of 3 kHz.

4 Temperature receive channel with a bandwidth of 560 Hz.

5 ECG receive channel with a bandwidth of 20 Hz.

Although the actual construction of a channel to measure the speed of the animal was not considered part of this project, an idea of how to go about it is presented in chapter 12 of this book.

CONTENTS PAGE

CHAPTER 1

THE OBJECTIVES OF THIS PROJECT:

1 System must process and transmit skin temperature of horse to the receiving end.

2 System must process and transmit the ECG measurement of the animal to the receiving end.

3 All tests must be done while the animal is in motion around the track to provide complete flexibility.

4 System will be installed at the Milnerton race track and must be able to operate effectively in this environment.

5 Processing equipment on the animal must be able to withstand shock treatment.

6 Apparatus must be relatively easy to operate by untrained people.

7 Temperature measurement must be accurate to within 0.5 °C.

CHAPTER 2

BIOMEDICAL ELECTRONICS

2.1 Background

The electronic apparatus that are to be designed in this book resort under the engineering field called Biomedical Electronics. In this fïeld electronic theory, technology, instrumentation, and computing systems are applied to biological research and medicine.

2.2 Historical Background

For the last half decade, along with the advantages of solid state electronic devices, integrated circuits, and microcomputers, the field has grown with great speed both in sophistication and diversification. The major contributions made and established are physiological monitoring and research, diagnostic instruments and imaging techniques, automated clinical laboratories, patient monitoring for the critically ill, prosthetic and orthotic devices, including artificial organs, computer data processing and management, and implant instrumentation systems.

2.3 Application

Electronic theory, technology and design procedures of devices, circuits, and systems can be matched and applied to biomedical applications with little or no modification, but two special topics are common to all biomedical electronics:

1 electrical safety
2 packaging and material.

Although no standard has been laid down in most countries, leakage current limits have been set with consideration of the physiological effects.
Packaging electronic devices for biomedical use must satisfy the following considerations in addition to ordinary industrial requirements.

1 The mechanical structure must be strong for use in a medical environment by non - engineering personnel.

2 Biocompatibility of the material must be ensured in order to protect the body in contact with the device from possible toxic effects.

3 The electronics must be protected from the body environment, which is much more corrosive than saline solution or seawater.

4 Size and weight limitations must be met.

CHAPTER 3

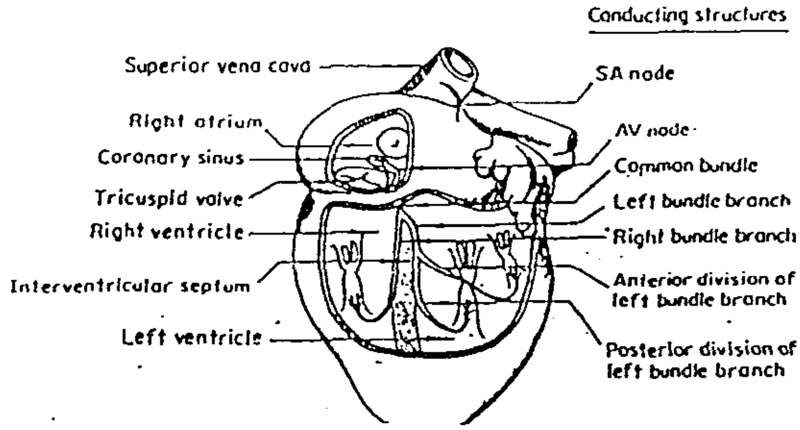
THE ECG SIGNAL

3.1 Introduction

Although the system design in this book is intended for application to horses, during research work reference was made to the human body. This was done firstly due to practical reasons, because a lot of experimentation is necessary, which makes the use of a human body more suitable, and secondly due to the similarities which exist between the human body and that of a horse as far as certain physiological characteristics are concerned. In this chapter the origin of the ECG signal and the conditions that have to met in processing the signal will be considered. A description of some of the difficulties encountered and how these were resolved will be given.

3.2 Origin of the ECG signal

The electrocardiographic (ECG) signals of importance to this project is generated by the heart.



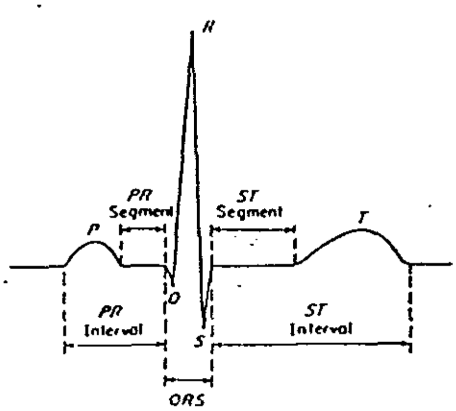
Cardiac muscle: structure and function

(Reference A: Page 64)

Fig. 3.I

The activation of all cells in the heart, initiated by the SA node, forms the basis for the ECG. Cells undergoing activation act as dipole current sources. The resulting local currents not only contribute to the spread of activity but also result in the presence of currents everywhere in the torso.

A typical ECG signal is shown in Fig. 3.2.



Standard scalar electrocardiogram

(Reference B: Page 64)

Fig. 3.2

Each of the three wave complexes, P, QRS, and T, corresponds to a particular electrophysiological event. A single cycle is in the order of 0.85 s, and the QRS duration is around 0.09 s, while the R - wave spike might cover an interval of 0.03 s.

CHAPTER 4

PROCESSING THE ECG SIGNAL

4.1 Problems common to ECG measurement

Before consideration can be given to designing a suitable ECG monitor, there are a few problems common to ECG measurement that need to be looked at first.

4.1.1 Ac Interference

One of the most persistent problems in ECG measurement is the reduction of ac interference. If the body is considered as a conducting sphere of 0.5 m radius, its capacitance to infinity is given by $C = 4\pi\epsilon(0.5) = 55$ pF, where ϵ is the relative permeability of free air. The capacitance to surrounding power line sources varies but is approximated at 100 pF. At the power line frequency of 50 Hz, this constitutes an impedance of 26 MΩ.

If the right leg is connected to the common ground of a high input impedance differential amplifier through an electrode with contact resistance of say, 2 kΩ, a power - line potential of 120 V will be reduced by the ratio of 2000/(26 X 10^6) to a value of around 10 mV as a noise input. This is a substantial signal, in excess of the ECG signal itself.

4.1.2 Base - Line Drift

A second major problem in ECG recording is that of base - line drift, which may arise from physiological tension or poorly connected electrodes. The patient should be lying down when recording ECGs, and freedom from noise or other distractions should be ensured.

4.1.3 Muscle Noise

Muscle noise normally only causes interference when the athlete is mobile during an exercising program.

4.1.4 Frequency Response

Inadequate high - frequency response can result in waveform distortion.

4.2 Designing the ECG channel

The design of a channel to do the initial processing of the ECG signal was aimed specifically at dealing with the problems mentioned above.

The essential part of a typical ECG - machine is a high - input impedance differential amplifier. The amplifier input maybe ac - coupled with a dc voltage balance control to balance off the difference in the dc base - line voltages of each electrode. By using differential amplifiers, the noise input caused by ac interference will be mostly eliminated, because normally each lead develops the same ac signal.

4.2.1 Body Electrodes

The electrodes used for this project are of the type that is normally used for measuring nerve stress. They were chosen because of their very high degree of sensitivity.

The electrodes are connected to the body as shown in fig. 4.1.

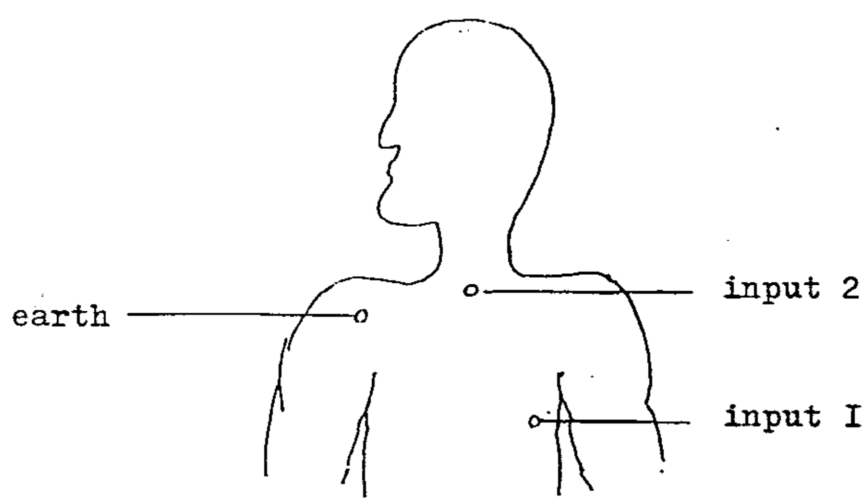


Fig. 4.I

Although the potential developed across the muscle cell membrane of the heart is in the vicinity of 90 mV, the voltage amplitude of the signal conducted into the leads was measured at 100µV only. The weak response was probably due to high body and electrode resistance.

4.2.2 Theory of Operation

The differential output from the electrodes are connected to the input of the ECG channel shown in fig. 4.2. This circuit constitutes the whole of the ECG channel made up of 9 stages.

Stage 1

This stage is based around a very high input impedance ($10^{12}\Omega$) op amp, the LF 442. This JFET input device is ideal for circuits like this where low power dissipation and good electrical characteristics are major considerations. The very high input impedance makes it very sensitive to low current signals and provides excellent gain. The amplifier circuit shown is configured to function as an integrator.

The input capacitance of the circuit, approximately 100 pF, is matched to that between the body and its immediate surroundings. Input impedance is greater than 2 X 10 MΩ and the input circuitry is designed to deal with frequencies of up to 60 Hz maximum.

Although the differential op amp configuration goes a long way towards dealing with noise at the input, it still only functions well under isolated conditions. This is due to the fact that the configuration has as its centre point body earth, and the moment the body comes in contact with surrounding objects, it causes a change in the capacitance of the surrounding electric field which again causes a

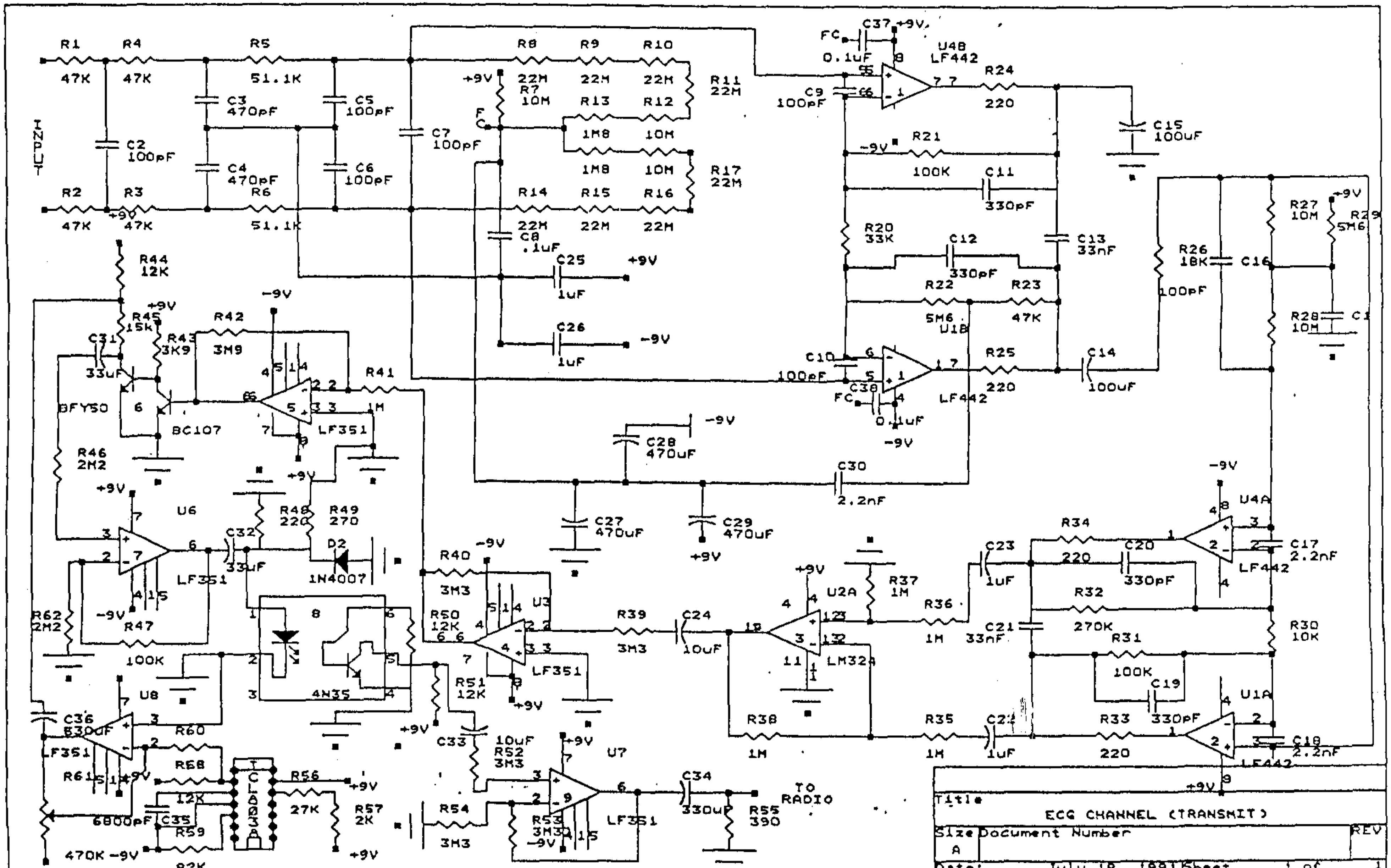

INPUT
R1 47K
R4 47K
R5 51.1K
R2 47K
R3 47K
R6 51.1K
C2 100pF
C3 470pF
C4 470pF
C5 100pF
C6 100pF
C7 100pF
R7 10M
R8 22M
R9 22M
R10 22M
R11 22M
R12 10M
R13 1M8
1M8
10M
R17 22M
R14 22M
R15 22M
R16 22M
C8 .1uF
C25 1uF
C26 1uF
FC
C37
0.1uF
C9 100pF
U4B LF442
R24 220
C15 100uF
R21 100K
C11 330pF
R20 33K
C12 330pF
C13 33nF
R22 5M6
R23 47K
U1B
C10 100pF
C38
0.1uF
LF442
R25 220
C14 100uF
R26 18K
C16 100pF
R27 10M
R28 10M
R29 5M6
C28 470uF
C30 2.2nF
C27 470uF
C29 470uF
R44 12K
R45 15K
R43 3K9
R42 3M9
R41 1M
C31 33uF
BFY50
BC107
LF351
R46 2M2
U6
C32 33uF
R48 220
R49 270
D2 1N4007
R47 100K
R62 2M2
4N35
R40 3M3
R50 12K
R51 12K
U3
LF351
R39 3M3
C24 10uF
U2A
LM324
R37 1M
R36 1M
R38 1M
R35 1M
C23 1uF
R34 220
C20 330pF
U4A
LF442
C17 2.2nF
R32 270K
C21 33nF
R30 10K
R31 100K
C19 330pF
R33 220
C22 1uF
U1A
LF442
C18 2.2nF
U8
C36 330uF
LF351
R60
R68
R61
12K
C35 6800pF
R59 82K
470K
CLA083A
R56 27K
R57 2K
C33 10uF
R52 3M3
R54 3M3
R53 3M3
U7
LF351
C34 330uF
R55 390
TO RADIO
Title
ECG CHANNEL (TRANSMIT)
Size A
Document Number
REV
Date: July 18, 1991
Sheet 1 of 1

Fig 4.2

change in the potential across the field. This will lead to the induction of noise emf's into the input leads. The result is severe variations and distortion in the input signal, leading to poor signal response.

Normally the animal is made to stand still on a rubber carpet thereby isolating it from earth. The above precautions could not be taken here as the animal had to be in motion. This undesirable effect was countered by inserting capacitors between body earth and the various supply rails. (C 27, C 28, C 29). Any potential variations in the surrounding field will charge up one of these capacitors. Due to their large capacitances they charge and discharge slowly, thereby causing a stabilizing effect on the body earth.

This configuration does push up the dc base - line voltage at the output of the op amps. However since futher circuitry is independent of this, it does not effect system operation as such.

To overcome the problem of base - line drift, at the output of stage 1, C 30 was connected to body earth. It is of a small value and therefore discharges the output quickly towards body earth after each output pulse. This prevents the dc - base line from slowly drifting upwards to saturate the amp.

C 15 connects the one output of the op amp to earth. This is done as part of a preparation process to reference the signal to normal circuit earth. C 14 simply serves as a dc blockage to prevent the 2nd stage from loading the 1st one. The complete stage 1 provides an amplification factor of about 2 000 so that the output provided is a negative spike of approximately 500 mV.

Stage 2

This stage is also based around the LF 442, but uses normal circuit earth as centre point compared to the body earth used by stage 1.

Stage 3

The purpose of this circuit is to change the differential output of stage 2 to a single output, which is referenced to normal circuit earth. It is based around the LM 324. This IC has certain advantages including large dc voltage gain, wide bandwidth, and very low supply current drain. It is also sensitive to low power signals due to its relatively high input impedance. No amplification takes place in this stage, however the signal does get inverted from a negative to a positive spike.

Stage 4

Stage 4 simply serves as an inverter and has no amplification factor.

Stage 5

This is another amplifier with a gain of 3.3. Both stages

4 and 5 are based around the LF 351. The LF 351 is a low cost high speed device ideal for use in application such as high speed integrators. The resistors connected to the input of the op amp must have a high resistance to maintain the high input impedance of the device.

Stage 6

Stage 6 is a latch circuit, consisting of two BFY 50 transistors. A 1 kHz square wave frequency, originating from a stable generator that will be described at a later stage, is latched by this circuit everytime a ECG pulse arrives from the previous stage. The frequency is applied to the latch on a constant basis to ensure stability.

Stage 7

This is a buffer circuit to prevent the latch from affecting any further stages.

Stage 8

Although the buffer circuit should theoretically isolate the latch from the output, it was found in practise that the adjacent temperature channel was effected by it, causing the tone coming from this channel to be clipped off everytime the latch operated.

To prevent this, an optocoupler, the 4N35, was included into the circuit to isolate the output completely from the rest of the circuit.

Stage 9

This stage serves as an output buffer and provides impedance matching to the input of the radio circuit.

4.2.3 Oscillator

Due to the accuracy of the equipment at the receiving end the oscillator must be very stable. Although rather expensive, the ICL 8038 is capable of producing high accuracy sine, square, triangular, sawtooth or pulse waveforms with a minimum number of external components.

It drives the latch via a buffer circuit based around the LF 351.
The output frequency is given by the formula:

$$f = \frac{0.15}{RC}$$

This completes the description of the ECG transmit channel. For any further information on technical specifications or theory of operation refer to the bibliography at the back of this text.

CHAPTER 5

TEMPERATURE MEASUREMENT SYSTEMS

5.1 Introduction

Together with the ECG signal it is also important to simultaneously record the skin temperature of the animal. This will aid the ECG test in creating a resultant which will give a broader prospective of the exact physical condition of the animal. Each individual animal's exercise program can then be adapted to ensure that it is in peak condition.

5.2 Temperature Measurement

In practise temperature measurement is normally done by having a thermometer inside the animal's rectum. However, since the signal needs to be processed electronically, a type of electrical signal is required.

5.3 Types of Temperature Measurement Systems

Two main types of temperature measuring systems are currently available. These are thermocouples and resistance thermometers. Sensors employing these techniques can be provided to fulfil most temperature measurement requirements. Thermocouples of different types can cover the range -250°C to 2000°C and beyond, while resistance thermometers can be highly accurate. The important characteristic of both methods is that the output is in the form of an electrical signal which can be readily transmitted, switched, displayed, recorded and further processed using suitable data handling equipment. What follows is a brief description on both these two concepts of temperature measurement.

5.3.1 Thermocouple Thermometry

5.3.1.1 Advantages

Wide temperature range
Versatile, e.g. sensor can be in a robust industrial unit of mineral insulated cable or as ultra fine wires, etc.
Simple application, just the junction at the tip needs to take up the required temperature.

5.3.1.2 Disadvantages

Requires a temperature reference.
Requires attention to detail for high accuracy.

5.3.1.3 Basic concepts

If a temperature gradient is presented in an electrical conductor, the heat will create a movement of electrons and an electromotive force (e.m.f.) will be generated in the region. The magnitude and direction of the e.m.f. will be dependant on the magnitude and direction of the temperature gradient and the material forming the conductor. The voltage existing along the ends of the conductor will represent the algebraic sum of the e.m.f.s generated along it. Thus for a given overall temperature difference, T1 - T2, the gradient distributions shown diagrammatically in Figures 5.1a, 5.1b and 5.1c will produce the same total voltage, E, providing that the conductor has uniform thermo - electric characteristics throughout its length.

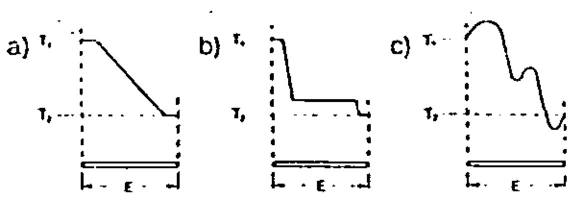


Fig. 5.I

(Reference B: Page 64)

The output voltage of a single conductor as shown is not normally measurable as the sum of the thermal e.m.f.s around a completed circuit of a uniform conductor, in any temperature situation will, of course be zero.

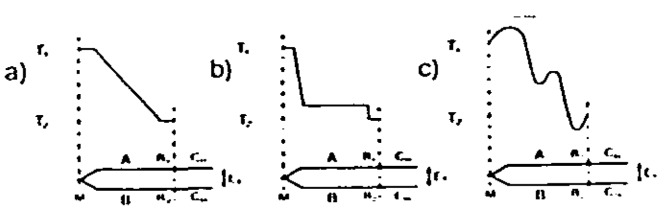


Fig. 5.2

(Reference B: Page 64)

In a practical thermocouple, two materials having different e.m.f./temperature characteristics are combined to produce a useable output voltage. Thus a thermocouple compromising two dissimilar conductors A and B in the temperature gradient situation shown in fig. 5.2a will generate an output because of the interaction of the temperature gradient with both conductors A and B. It will produce the same output, E_T for any gradient distribution between a given temperature difference T1 - T2 provided that the conductors have uniform thermo - electric characteristics throughout their lengths (Figs. 5.2a, 5.2b and 5.2c).

As the junctions M, R1, R2, represent the limits of the e.m.f. generating conductors A and B, and since the remaining conductors linking the measuring device being copper wire, the output of the thermocouple will effectively become a function of the junction temperatures. This is the basis of practical thermocouple thermometry.

A thermocouple, then, provides an output that is related to the temperatures of its two junctions. It is usual to designate the connection between the two dissimilar wires as the Measuring Junction and the junction linking the dissimilar wires to the copper output connections as the Reference Junction (M and R, respectively in Figure 2). If the reference junction is maintained at a fixed and known temperature, the temperature of the measuring junction can be deduced from the thermocouple output voltage. Calibration tables are available for each thermocouple combination that relate output voltage to the temperature of the measuring junction if the reference junction is maintained at 0°C.

5.3.1.4 Characteristic of Summary

a) The output of a thermocouple is generated only in the regions where temperature gradients exist along it.

b) To ensure accurate and stable operation the thermo - electric characteristics of the thermocouple conductors must be, and remain, uniform throughout.

c) Only a circuit compromising dissimilar materials in a temperature gradient will generate an output. A circuit compromising a single uniform conductor situated in a temperature gradient will produce no output.

d) The thermo - electric sensitivity of most materials is non - linear with temperature. Thus a given temperature difference between the measuring and reference junctions of a thermocouple will produce different outputs at different reference temperatures.

5.3.2 Resistance Thermometry

5.3.2.1 Advantages

Potentially the most accurate method.
Simple installation.

5.3.2.2 Disadvantages

Requires an energizing current.

Sensor types limited

High accuracy types requires careful handling.

Sensors are physically larger than thermocouple junctions.

5.3.2.3 Basic concepts

The resistance that electrical conductors exhibit to the flow of an electrical current is related to their temperature.

If the relationship is predictable, smooth and stable, the phenomenon can be used as a basis for temperature measurement. There are some metals that fulfill this requirement including copper, gold, nickel, platinum, and silver. Of these copper , gold and silver have inherently low values of electrical resistivity making them less suitable for resistance thermometry, although copper has almost a linear resistance relationship with temperature. Nickel and nickel alloys have a high resistivity and high resistance versus temperature coefficients but these are non - linear and sensitive to strain.

This leaves platinum which has advantages which make it well suited to resistance thermometry. It has a wide temperature range, a resistivity that is more than six times that of copper and a reasonable although non - linear resistance versus temperature coefficient. It can be drawn into fine wires or strips and can also be obtained in a very pure form. Although platinum is a very expensive material, only small amounts are required for resistance thermometry construction and this is not a highly significant factor in the overall cost.

5.4 Factors influencing the choice of a sensor

5.4.1 Requirements

The method has to be accurate, but only over a narrow temperature range.
It must result in the most simplistic processing apparatus possible.

It is therefore obvious that a method supporting the Resistance Thermometry technique is the best one to use.

5.5 Chosing a Probe

5.5.1 Requirements

The sensor must be suitable for biomedical use.
It must provide some type of an electrical signal.
It must cause as little as possible inconvenience to the animal.
It must be isolated from any surrounding conditions.
It has to be as linear as possible to ease further processing.

The best way to meet the set requirements is to measure the animal's skin temperature, and by having it isolated from atmospheric conditions, it will give a rather true representation of the animal's actual temperature.

After a somewhat lengthy search and a good amount of experimentation, it was decided to make use of a temperature sensor produced by a company called " Yellow Springs Instruments. "

The probe that was selected the best for the intended purpose is the YSI 409A. It is called the " Banjo " Surface Temperature probe and has been designed specifically for measuring skin temperature. This stainless steel probe is useable for temperatures up to 150 °C and has a time constant of 0.6 seconds.

Table 5.1 gives an indication of the temperature versus resistance ratio of this probe.

TEMP °C	RES OHMS	TEMP °C	RES OHMS	TEMP °C	RES OHMS
-40	75.79K	12	4075	31	1740
-35	54.66K	13	3887	32	1668
-30	39.86K	14	3708	33	1599
-25	29.38K	15	3539	34	1534
-20	21.87K	16	3379	35	1471
-10	16.43K	17	3226	36	1412
- 5	12.46K	18	3082	37	1355
0	9534	19	2944	38	1301
1	7355	20	2814	39	1249
2	6990	21	2690	40	1200
3	6319	22	2572	41	1153
4	6011	23	2460	42	1108
5	5720	24	2354	43	1065
6	5444	25	2253	44	1024
7	5184	26	2156	45	984.2
8	4937	27	2065	46	946.6
9	4704	28	1977	47	910.6
10	4483	29	1894	48	876.2
11	4273	30	1815	49	843.2

Table 5.I

CHAPTER 6

PROCESSING THE TEMPERATURE SIGNAL

6.1 Introduction

To convert the measured temperature into an electric signal, the temperature probe is normally incorporated into a Wheatstone bridge configuration as shown in Fig. 6.1.

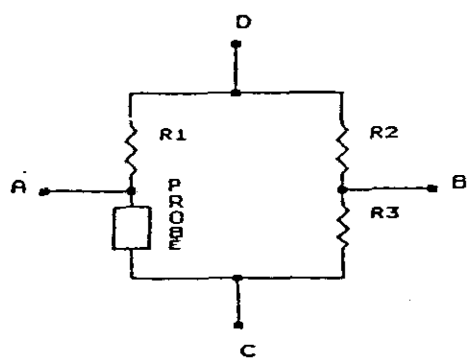


Fig. 6.I

A fixed voltage is applied across C & D. When the resistance of the probe changes due to a change in temperature, the voltage measured across A & B will change as well. A varying temperature will therefore cause a slowly varying dc signal across A & B.

This varying dc signal can then be processed in a number of ways, including the use of amplitude modulation, voltage controlled oscillators (VCO), etc.

6.1.1 Amplitude Modulation

Advantages

The modulator circuit is rather simplistic.

Disadvantages.

Synchronization must be maintained between the modulating and demodulating circuits in order to ensure that accurate measurements are being taken by the receiving end. Modulation depth must be restricted to a certain limit to prevent modulation distortion.

6.1.2 Voltage Controlled Oscillator (VCO)

Advantages

VCO's are available as one complete integrated circuit (IC).
Low power consumption.

Disadvantages

Can only be used for the transmission of a singular signal.

To simplify circuitry as far as possible, and because it is only necessary to process a single signal, it will be best to make use of a VCO.

6.2 Temperature Channel (Transmit)

Refer to Fig. 6.2

The complete channel consists of 6 stages.

Stage 1

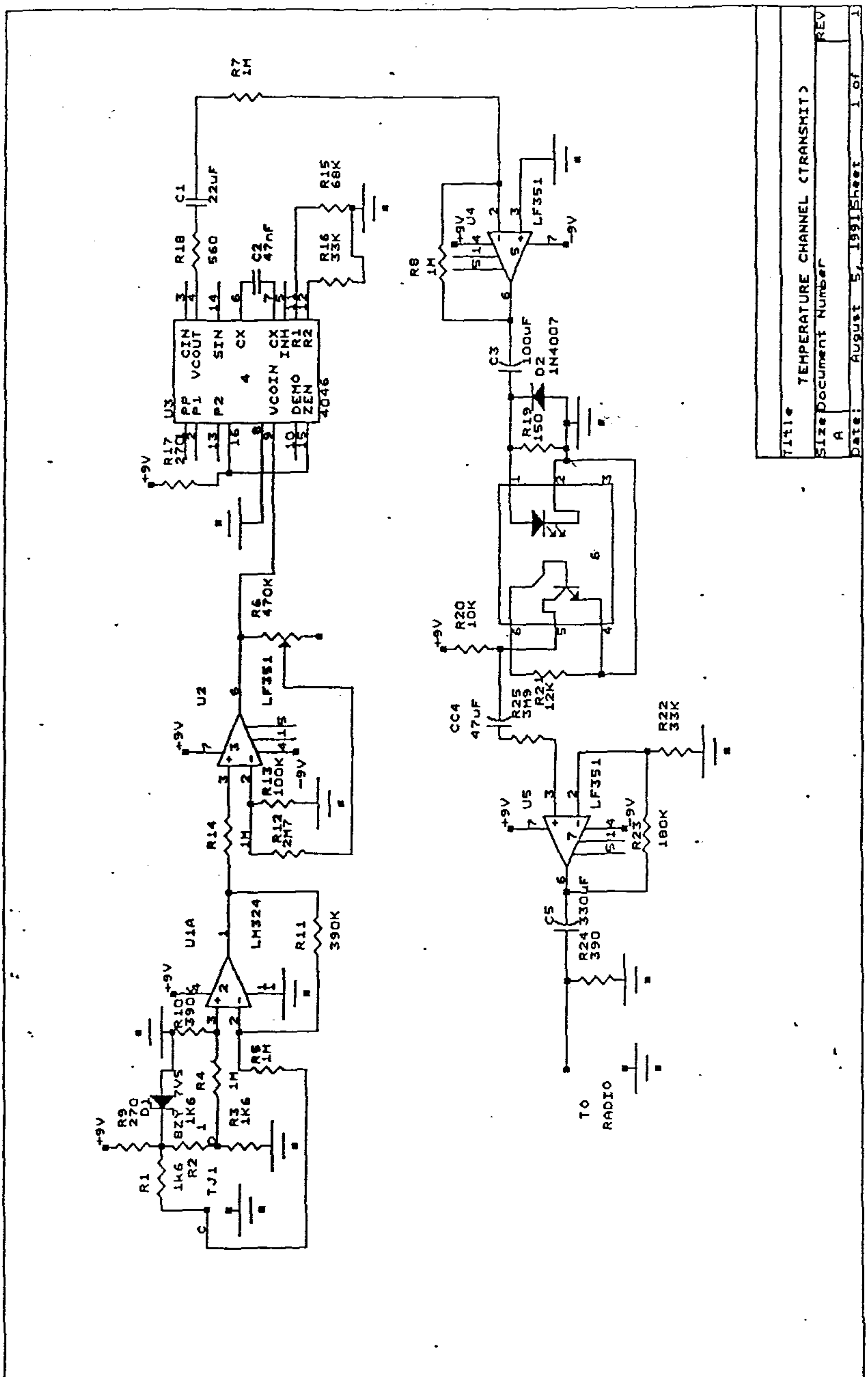
The temperature probe is connected to TJ1 and forms part of a Wheatstone bridge configuration together with R1, R2, and R3.

The bridge will be in balance when the probe has a resistance of 1600 Ω. The output of the bridge at this stage will be 0 Volt and this will be set to represent a temperature of 33°C. If the resistance of the probe changes, due to a change in temperature, the differential dc voltage delivered by the bridge will change as well. The channel is designed to handle a temperature band of between 33°C and 42°C.

The transmit side is mobile and battery driven. The zener diode (D1) is necessary to maintain a stable voltage across the wheatstone bridge in case of a possible drop in battery voltage. This will ensure accurate measurements up to a minimum battery voltage of 7.8 V.

Stage 2

This stage consists of a differential op amp based around the LM 324. Its purpose is to determine the voltage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TEMPERATURE CHANNEL (TRANSMIT)
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TO RADIO

Fig 6.2

difference between C and D. Table 6.1 indicates the temperature versus probe resistance versus voltage ratio at the output of this stage when R10 and R11 have the normal value of 1 MΩ each.

TEMPERATURE	RESISTANCE	OUTPUT VOLTAGE	DIFFERENCE
42°C	1108	4.64 V	******
41°C	1153	4.77 V	130 mV
40°C	1200	4.90 V	130 mV
39°C	1249	5.04 V	140 mV
38°C	1301	5.18 V	140 mV
37°C	1355	5.33 V	150 mV
36°C	1412	5.48 V	150 mV
35°C	1472	5.63 V	150 mV
34°C	1534	5.78 V	150 mV
33°C	1599	5.96 V	160 mV

Table 6.I

6.2.1 Linearity

The above table indicates that the temperature versus voltage ratio is not linear. For example, the difference between 39°C and 40°C is a 140 mV compared to 130 mV between 40°C and 41°C. Corresponding resistance changes, being 49 Ω and 47 Ω respectively, shows that this is caused by a non - linear temperature probe. The change in resistance is not linear throughout the band and therefore would not be solved by the use of a normal anti - logarithmic amplifier.

This difference is however not severe enough to push the accuracy out of limits. Stage 2 is set to have a loss of 2.5 times to reduce this difference and further amplification stages also take this difference into account.

TEMPERATURE	RESISTANCE	OUTPUT VOLTAGE	DIFFERENCE
42°C	1108	1.851 V	******
41°C	1153	1.900 V	49 mV
40°C	1200	1.949 V	49 mV
39°C	1249	2.002 V	53 mV
38°C	1301	2.055 V	53 mV
37°C	1355	2.112 V	57 mV
36°C	1412	2.169 V	57 mV
35°C	1472	2.226 V	57 mV
34°C	1534	2.283 V	57 mV
33°C	1599	2.347 V	64 mV

Table 6.2

Table 6.2 is the same as table 6.1. The readout of table 6.2 was obtained with R10 and R11 equal to 390 kΩ each.

Stage 3

This is a high input impedance dc amplifier that drives the voltage controlled oscillator (VCO). Its purpose is to amplify the slow varying dc signal to a level just enough to cause a sufficient swing in the VCO frequency.

Stage 4

The CD4046 is a highly stable VCO set to have a free running frequency of 1.09kHz and a frequency swing of 1.09 kHz (33°C) to 1.65 kHz (42°C). The free running frequency is determined by C2, R15 and R16. This part of the circuit acts as a modulator to convert the changes in dc voltage obtained to corresponding changes in frequency. Vcc is regulated by a zener diode to prevent a drop in supply voltage from affecting the output frequency.

Stage 5

This buffer circuit prevents the output of the VCO from being loaded by the next stage.

Stage 6

The 4N35 optocoupler is included in the circuit as an extra precaution to prevent the latch circuit of the adjacent ECG channel from affecting the output frequency of the VCO. The input amplitude to the optocoupler is limited by R19 and D2.

Stage 7

This output buffer provides impedance matching to the input of the radio circuit.

CHAPTER 7

RADIO TRANSMISSION

7.1 Requirements

1 Must be able to transmit the ECG and Temperature information effectively over the range required.

2 Bandwidth must provide space for the adding of more tests in future, if required.

3 Transmitter must be fully mobile and as light as possible.

4 Power consumption must be as low as possible.

5 Must have good signal to noise ratio.

7.2 Types of Modulation

The following types of modulation were considered.

7.2.1 Pulse Code Modulation

Pulse code modulation is normally only used where a multiple number of channels have to be transmitted over a single channel radio on a time multiplexed basis. This involves quite complex circuitry and synchronization is of the utmost importance.

7.2.2 Phase Modulation

Phase modulation and frequency modulation are inseparable. Phase modulation is more difficult to detect than frequency modulation and is not often used.

The two most viable options left are amplitude modulation and frequency modulation.

7.2.3 Amplitude Modulation

7.2.3.1 Advantages

Simpler modulating and demodulating circuits

7.2.3.2 Disadvantages

Modulation depth must be restricted to about 90% to prevent modulation distortion from occurring.

7.2.4 Frequency Modulation

7.2.4.1 Advantages

Good signal to noise ratio.
Less distortion.

7.2.4.2 Disadvantages

Modulating and demodulating circuitry is rather complex.

The 27 MHz frequency band, where most two - way radios operate in, is the only band in which space could be acquired from the Department of Post & Telecommunications.

Attempts to acquire space in the 144 MHz frequency band where most FM two - way radios operate in were unsuccessful.

Since the transmitter and the receiver will operate in line of sight over a maximum distance of 1.5 km, a very good signal to noise ratio is not important.

Both the signals from the two channels are fed to the transmitter in a simplified modulated form, which makes it easier to detect them at the receiving end, even with a poor signal to noise ratio.

Therefore it was decided to make use of an AM two - way radio system.

CHAPTER 8

TRANSCEIVER

8.1 Introduction

It was mentioned in the previous chapter that the radio circuit should provide space for further expansion in future if necessary.

Therefore it was decided that both ends must be equipped with a transmitter and a receiver to provide for future tests which may require data transmission in both directions.

A circuit diagram of the transceiver decided upon is given in Fig. 8.1

The transceiver is an amplitude modulated system operating in the 27 MHz Citizens Band with an IF frequency of 455 kHz. Power output to line is 0.5 Watt, which will be adequate, since the transmitter and receiver will operate in line of sight over a maximum distance of not more than 1.5 km at all times.

SCHEMATIC DIAGRAM

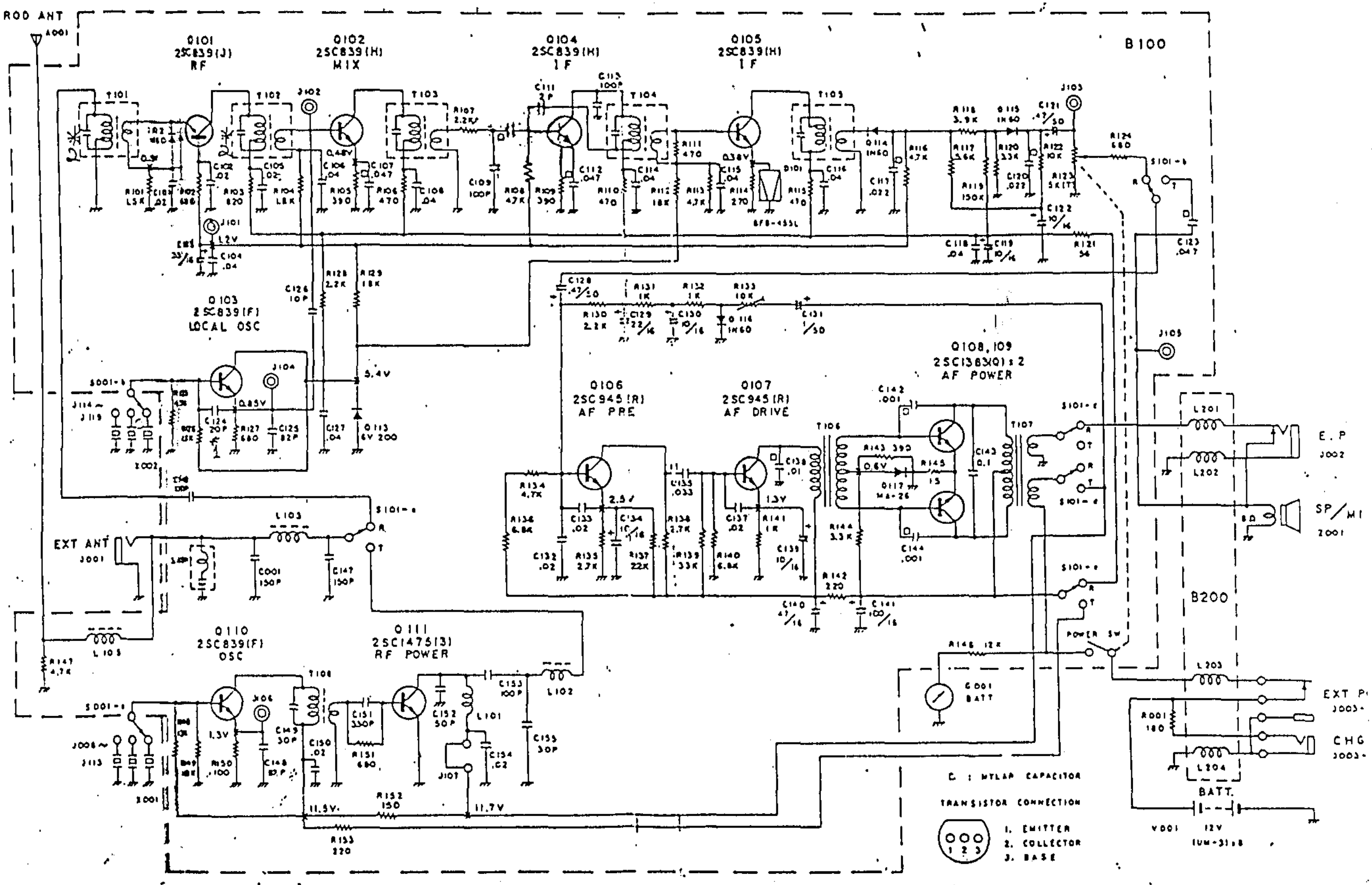


Fig 8.I

8.2 Theory of operation

8.2.1 Transmit

The outputs from the Temperature and ECG channels are connected to the speaker input of the transmitter. It was decided to use a speaker instead of a matching coil at the input. During fault finding, it will provide a audible indication as to whether a signal from the faulty channel is outputted to the transmitter or not.

The signal then passes through a low pass filter with a cutoff frequency of 3 kHz.

The audio frequency amplifier section consists of the pre - amplifier (Q106), the driver amplifier (107), and the differential power amplifier (Q108,Q109) and is common to both the transmit and receive sections. The one leg of its differential output drives the speaker in the receive direction. The other leg provides a modulating signal to the modulator circuit during a transmission cycle. The modulating circuit is formed with Q110 as the active element.

Q110 is configured to be a Colpitts oscillator which is crystal controlled and set to run at a frequency of 27.015 MHz. The modulated output carrier is fed to the line power amplifier (Q111) and then passes via a low pass filter to the antenna.

8.2.2 Receive

The signal from line is fed via a low pass filter to the radio frequency power amplifier (Q101). It is then demodulated by Q102 to provide an IF frequency of 455 kHz. This IF frequency is amplified by Q104 and Q105. The output of Q105 is demodulated to provide an audio output. This audio output is then amplified by the common audio channel from where it is fed to the respective receive circuitry.

CHAPTER 9

RECEIVING THE ECG SIGNAL

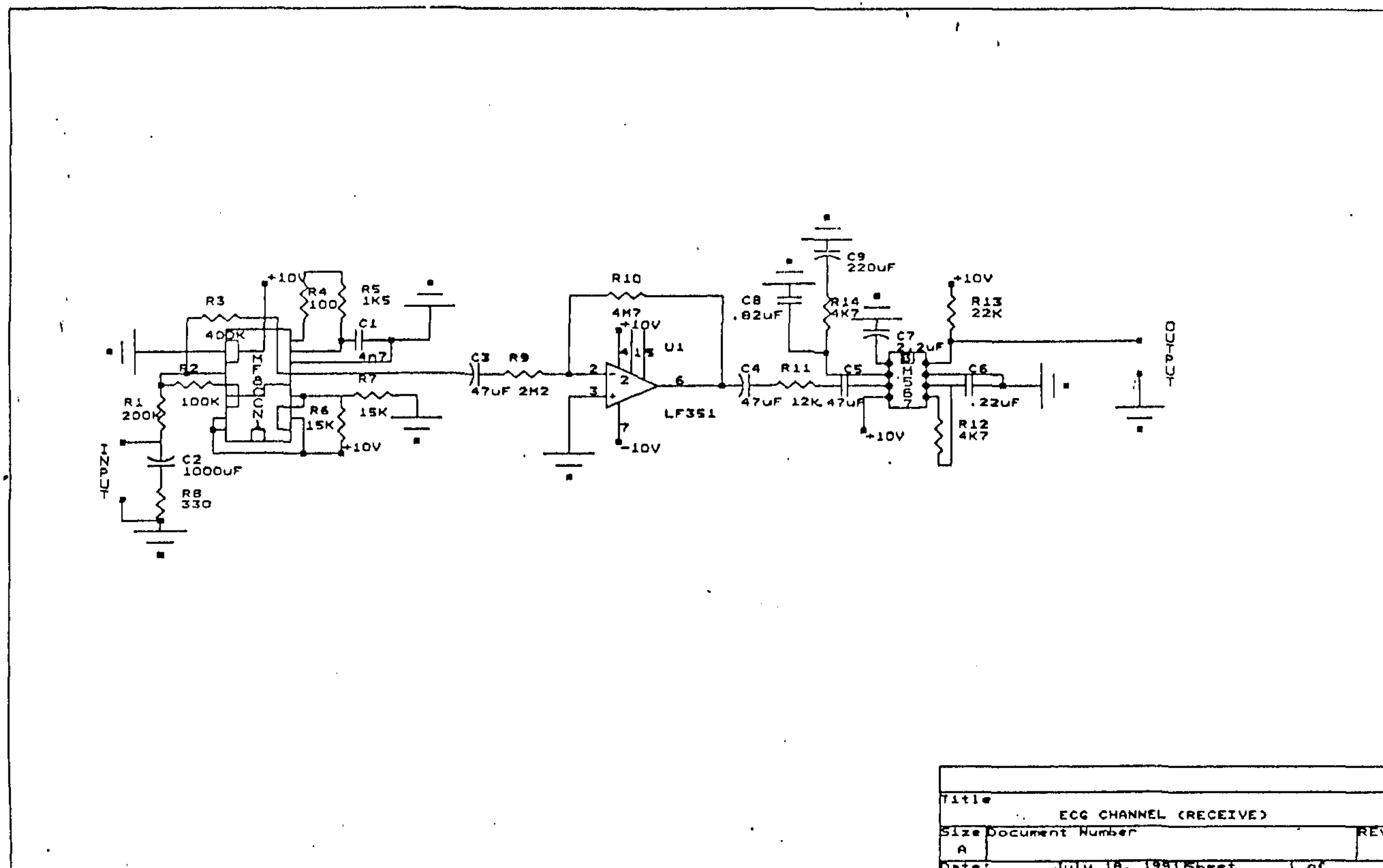
9.1 Requirements

There are various ways in which the 1 kHz bleep that originates from the ECG pulse can be detected at the receiving end. The detector, must provide a +5V dc pulse everytime this 1 kHz bleep occurs. This 5V pulse can, through the necessary interfacing, be captured by a personal computer for later use. The heart rate can also be displayed by a digital instrument to give a dynamic indication thereof.

9.2 ECG Channel (Receive)

Refer to Fig. 9.1

At the input C2 and R8 is used to suppress most of the noise present in the receive signal. These two components are common to the input of both the ECG and Temperature channels. They will prevent high level noise spikes from accidentally triggering the detection circuit.


R3
400K
R2
100K
R1
200K
C2
1000uF
R8
330
INPUT
+10V
R4
100
R5
1K5
C1
4n7
R6
15K
R7
15K
+10V
C3
47uF
R9
2M2
R10
4M7
+10V
U1
LF351
-10V
C4
47uF
R11
12K
C5
47uF
C8
.82uF
C9
220uF
R14
4K7
C7
2.2uF
+10V
R13
22K
C6
.22uF
R12
4K7
OUTPUT
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ECG CHANNEL (RECEIVE)
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Fig 9.I

Stage 1

The 1 kHz frequency bleep is then selected by a 4th order band pass filter based around the MF 8CCN. The filter has a centre frequency of 1 kHz.

The centre frequency (fo), is controlled by an internal CMOS clock generator and the ratio between the two is set at 100:1. The clock frequency is determined by C1 and R5. The Q of the filter can be programed by connecting each of pins 1, 2, 3, 17 and 18 to either Vcc or earth. (See data sheets in appendix A.)

Stage 2

The purpose of the amplification stage, based around the LF 351, is to amplify the output from the filter to a level high enough to drive the detection circuit effectively. The detection circuit is set to react on an input amplitude of 200 mV minimum. It also serves as a buffer stage between the filter and the detection circuit.

Stage 3

The LM 567 is configured as a tone decoder and is set for a bandwidth of 1 kHz ± 10Hz. The circuit consists of a Q detector driven by a voltage controlled oscillator which determines the centre frequency of the decoder. The centre frequency is determined by R12 and C6. The bandwidth is determined by the amplitude of the input signal, the centre frequency and C8.

Reaction time of the IC depends on the detection bandwidth it is set for. The wider the bandwidth, the longer it will take to respond. To give a proper and quick response to the short frequency bleep caused by the ECG pulse, it was found in practise that the detector circuit had to be set to a bandwidth of about 10 Hz.

When a 1 kHz tone is detected at the input, the output of the circuit will change to a stable +5V dc level and this condition will be maintained until the tone is removed. A series of ECG pulses at the transmitting end will therefore produce a series of +5V dc pulses at the receiving end.

CHAPTER 10

RECEIVING THE TEMPERATURE SIGNAL

10.1 Requirements

The temperature must be displayed on a LCD display.

The reading must be as stable as possible.

Measurement must be accurate to 0.5 °C.

As mentioned in chapter 5, the varying temperature of the athlete is converted into a varying frequency before transmission. To process this signal at the receiving end, two methods were considered.

10.2 Methods

10.2.1 Integration

The received signal is integrated to convert its frequency to amplitude. The voltage amplitude is an indication of the temperature. This volatage can then be further processed to drive the LCD display.

To produce an accurate result, the integrator must be triggered at exactly the right moment. The amplitude of the input signal from the radio receiver must be kept stable to produce an accurate result. This is not possible with a radio transmitted signal which is constantly prone to fading caused by obstacles in the radio pathway.

10.2.2 Phase Locked Loop

All phase locked loop circuits consist of a voltage controlled oscillator and a phase detector. If a frequency is present at the input of the phase detector, it will issue a VCO control voltage (dc) to lock the frequency of the internal VCO unto the frequency at the input. If the frequency at the input changes, the VCO control voltage will change accordingly. The circuit therefore functions as an FM demodulator and the analog dc voltage from the phase detector can easily be converted to digital to drive a LCD display.

10.3 Temperature Channel (Receive)

Refer to Fig. 10.1

10.3.1 Theory of operation

At the input C2 and R8 suppress the low frequency noise present in the signal from the AM receiver.

with a radio transmitted signal which is constantly prone to fading caused by obstacles in the radio pathway.

10.2.2 Phase Locked Loop

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10.3 Temperature Channel (Receive)

Refer to Fig. 10.1

10.3.1 Theory of operation

At the input C2 and R8 suppress the low frequency noise present in the signal from the AM receiver.

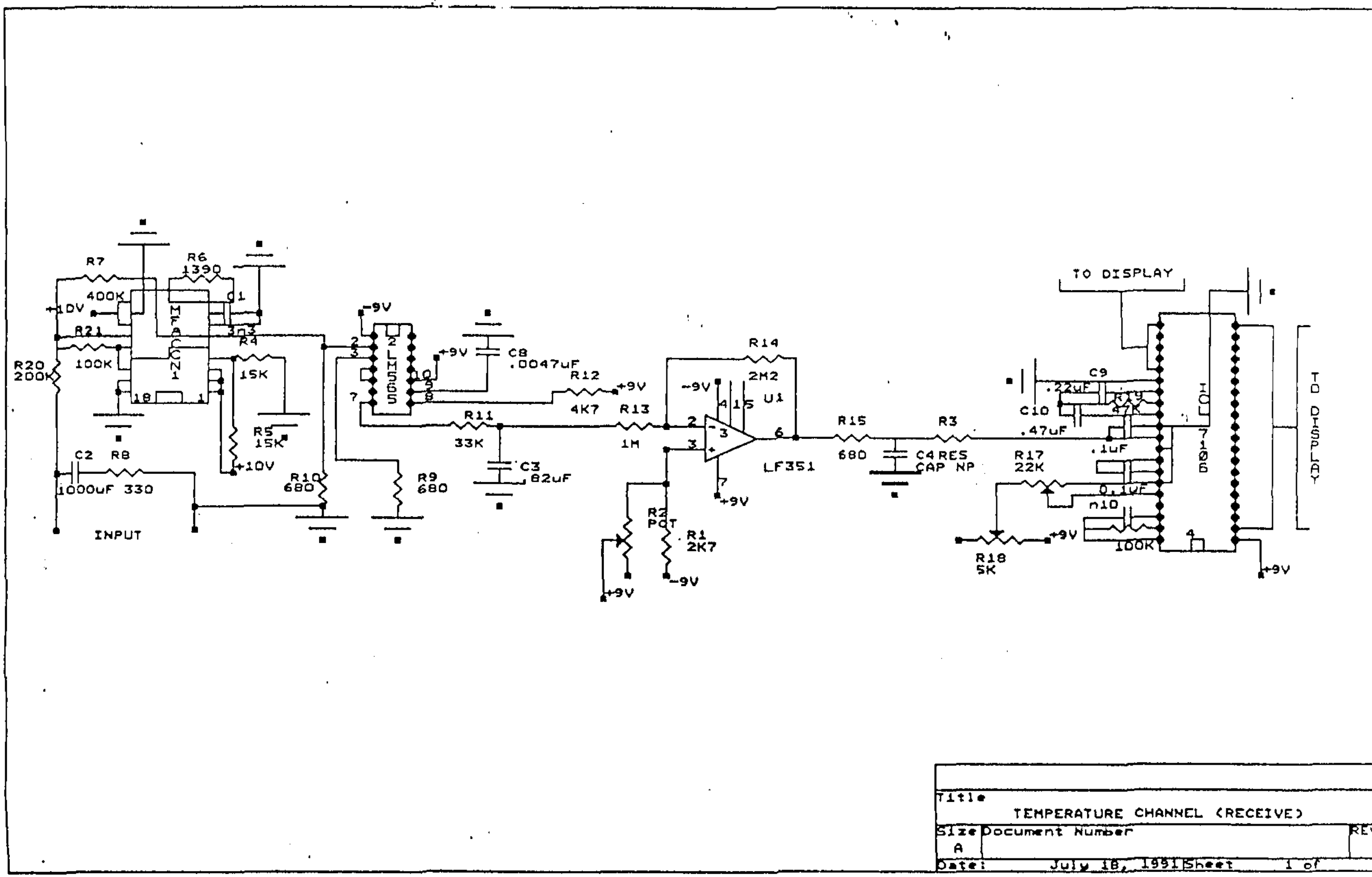
TO DISPLAY
TO DISPLAY
INPUT
LM565
LF351
U1
R7
400K
R6
1390
R21
100K
R4
15K
R5
15K
R20
200K
C2
1000uF
R8
330
R10
680
R9
680
R11
33K
C3
82uF
C8
.0047uF
R12
4K7
R13
1M
R14
2M2
R15
680
C4 RES
CAP NP
R3
R2
POT
R1
2K7
C9
.22uF
C10
.47uF
.1uF
R17
22K
0.1uF
n10
100K
R18
5K
7106
+10V
-9V
+9V
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Fig IO.I

Stage 1

The temperature input signal is then selected by a 4th order bandpass filter based around the LM565. The operation of a similar filter has already been discussed in section 8.2. Cut off frequencies is set at 1.09 kHz at the bottom and 1.65 kHz at the top. The filter has a Q of 4.

Stage 2

The output of the filter is fed to the phase detector input of the LM565. This IC is a general purpose phase locked loop and has a stable, highly linear voltage controlled oscillator. The free running frequency of the VCO is determined by C8 and R12 and is set at 1.09 kHz which is the same as the lowest frequency possible at the input.

If the frequency at the input increases due to an increment in temperature of the mobile athlete, the dc voltage at the VCO control voltage output will rise accordingly. This dc voltage will charge C3 via R11 to produce a smooth and stable dc output. The complete circuit therefore functions as a FM demodulator.

Stage 3

The LF351 is configured as a high input impedance dc amplifier. Gain is controlled by R2 and is set to a value high enough to drive the analog to digital converter over the range required.

Stage 4

Analog to digital conversion is performed by the ICL7106. This IC has all the necessary decoders, display drivers and clocks on board to drive a 3½ digit LCD display.

The circuit is designed to give a full scale deflection with 200 mV at the input and will update the display 3 times per second. The value of the full scale deflection is determined by the values of the integrating capacitor C9, the integrating resistor R19 and the auto - zero capacitor C10. The significance of these components is explained on page 91 of Appendix A.

Although the display is actually indicating volts, it will be graded in degrees Celsius. The complete channel will be set up to indicate a value of 33 °C on the display when the minimum frequency of 1.09 kHz is present at the input of the channel. This will increase as the input frequency increase, until a maximum reading of 42 °C is reached at 1.65 kHz.

10.4 Problems Experienced

During full system operation it was found that the temperature display was affected by the signal of the adjacent ECG channel.

This seemed to happen everytime an ECG pulse from the radio receiver arrived at the input of the two channels, causing a clipping of about 2 °C on the display. At first the filters were investigated to make sure that no leakage could occur from one channel to the other.

Lowering the output level of the radio receiver resulted in a slight improvement, but seemed to decrease the range of the temperature channel. This seemed strange, because the phase locked loop circuit is frequency and not level sensitive.

Experimenting with the amplification stages to match the output level of the two signals at the transmit side properly, brought no improvement.

The operating frequencies of the two channels were than separated further away from each other to ensure proper discrimination by the filters.

When no improvement occurred, the possibility of noise induction from the ECG channel to the temperature channel was investigated.

It was then found that everytime the ECG latch at the transmit side operated, a certain amount of noise was generated on the output speaker of the receiver. The noise was then passed by the filter. This resulted in a severe variation in the VCO frequency of the phase locked loop, causing the clipping effect on the temperature display.

The problem was solved by replacing the speaker by a suitable RC - network.

CHAPTER 11

POWER

11.1 Introduction

The transmit side of the PDL is mobile and will therefore be battery driven.

At the receive side a ± 10 V supply is required for the channel circuitry and a +12 V supply for the radio receiver.

These supplies must be capable of providing 180 mA and a 150 mA respectively. Fig. 11.1 indicates a circuit diagram of a suitable power supply.

11.2 Theory of Operation

T1 reduces the 220 V ac to 10 V ac. It provides a centre tap and two 10 V ac tappings. The two ac tappings are fed to a bridge rectifier to provide a split ± 14.14 V with the centre tap from the transformer as earth. C1 and C2 removes any ac ripple present on the negative and positive supply lines respectively.

From the ± 14.14 V a + 12 V, + 10 V and a - 10 V is supplied by the LM7812, LM7810 and LM7910 respectively.

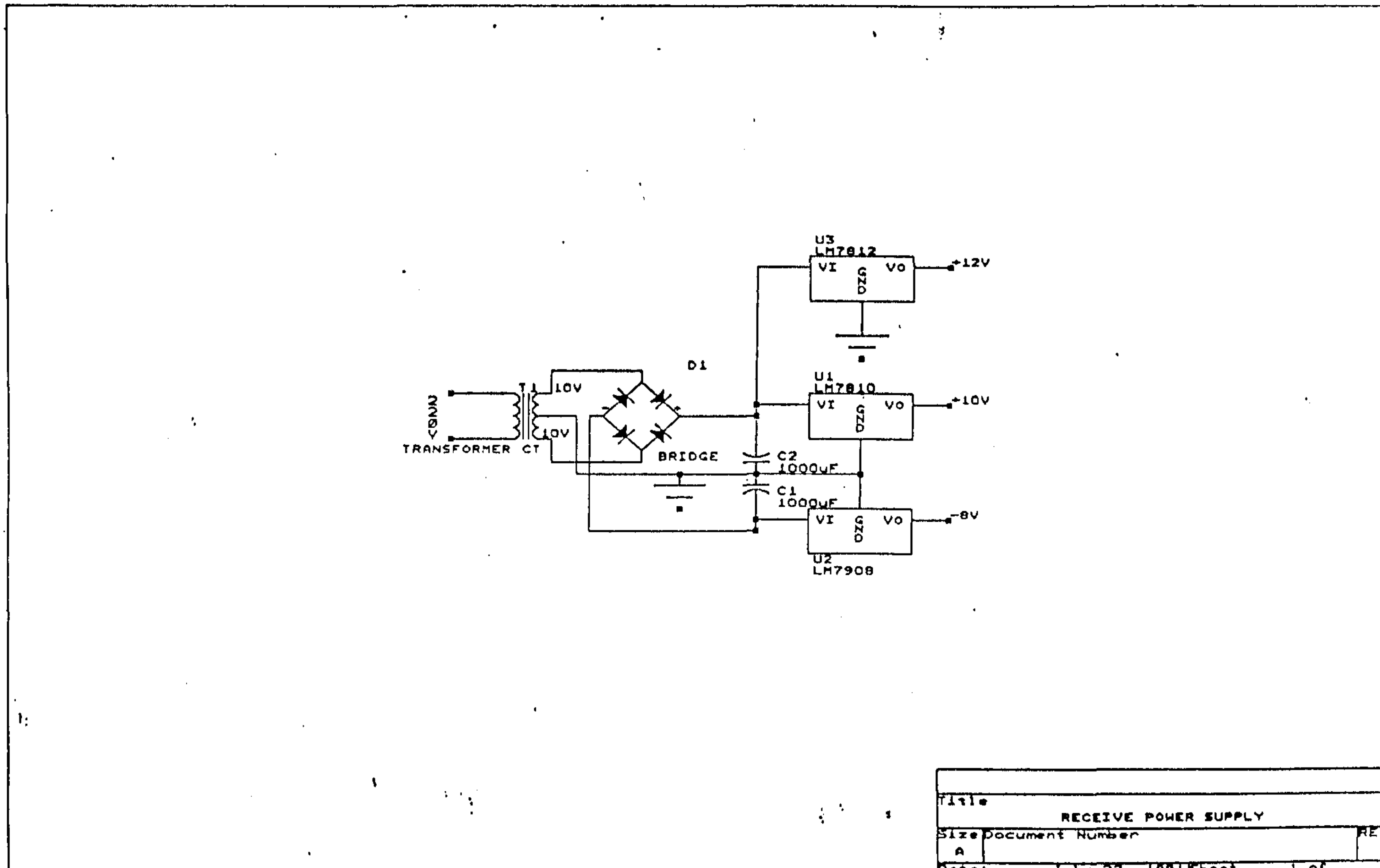
U3
LM7812
VI
GND
VO
+12V
U1
LM7810
VI
GND
VO
+10V
U2
LM7908
VI
GND
VO
-8V
D1
BRIDGE
C2
1000uF
C1
1000uF
T1
10V
10V
220V
TRANSFORMER CT
Title
RECEIVE POWER SUPPLY
Size
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Fig II.I

These transistors are capable of providing their respective regulated voltages at a maximum current drain of 1.5 A.

11.3 Problems Experienced

During construction, the PDL System was run from a normal portable bench power supply.

Since the power supply designed for the system provided the same voltages, no problems were expected as long as the supply met the requirements as far as current supplies and noise limitations were concerned.

However, when the PDL was run from the system supply it was found that while the ECG channel operated without problems, the temperature channel was affected. When the temperature of the athlete at the transmitting end increased, the LCD display at the receive showed a decrement in temperature. It was found that with the system supply the VCO of the phase locked loop was running at 765 Hz compared to 1.09 kHz with the bench supply. This resulted in a negative going VCO control voltage when the incoming signal increased in frequency.

Operating the temperature channel alone and bypassing the filter circuit at the input of the receive seemed to cure the problem, leading to the conclusion that something was wrong at the filter circuit.

However the response of the filter was the same with both power supplies and none of them caused any dc component to be present at the output of the filter.

It was then found that with the system supply, a lower level of high frequency noise was present at the output of the filter circuit, resulting in a decrease in the VCO frequency. To cure the problem, the VCO frequency had to be readjusted to 1.09 kHz when a signal of 1.09 kHz was present at the input of the channel.

CHAPTER 12

SPEED MEASUREMENT

12.1 Requirements

The method used must be able to select one animal out of a group and then indicate its speed.

The method must be at least 90% accurate.

Various methods were considered and although it was not considered as part of the project to actually construct a speed measuring device, the following ideas are proposed.

12.2 Methods

12.2.1 Infra Red

Infra red transmitters can be installed at regular intervals (±10 meters) around the track. The time taken by the animal to break two successive infra red beams will be an indication of its average speed over the interval. The disadvantage of the system is that it will not be able to select one animal if a group brakes the infra red beam.

12.2.2 Ultrasonic

The use of ultrasonic waves were not considered, because most systems operate in the 32 kHz band and the animal's are too sensitive to these frequencies.

12.2.3 Radar

Due to the fact that the animals are running on a grass service reflection will be a problem and to use reflection plates at regular intervals around the track will cause problems with angles of reflection.

The last option considered is closely related to the first method using infra red, except that a different medium is made use of. The infra red transmitter is replaced by an oscillator circuit capable of generating 6 different frequencies from 1 MHz upwards. These frequencies will then be radiated through an antenna with a very high Q factor over a distance of about 10 meters. A group of 6 horses will then each have a filter circuit tuned in for one of the 6 frequencies only. When the frequency is detected, a bi - stable latch will be activated which will start a counter. At the next interval the detected frequency will cause the bi - stable latch to be de - activated, stopping the counter. The resulting count can then send to the receiving station for further analysis to determine the average speed over the interval covered.

Although very expensive, this system seems to be the most viable method under the circumstances.

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