BIOTELEMETRY SYSTEMS AND THE DESIGN OF A LOW COST MICROPROCESSOR CONTROLLED RADIOTELEMETRY SYSTEM

by

M. Fatih Colgar

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APPROVED BY

Doc. Dr. Avni Morgul ____________________
(Thesis Supervisor)

Prof. Dr.Necmi Tanyolac ____________________

Y.Doc.Dr. Omer Cerid ____________________

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ÖZET

Bu tezde, giriş bölümlerinde genel olarak Biotelemetri sistemleri hakkında bilgi verildikten sonra özel bir Biotelemetri tasarımı örneği verilmiş, çeşitli alt bloklarda karşılaşılan problemler ve bunların çözümü incelenmiştir.

Bu tezde tasarımı yapılan ve ortaya çıkarılan sistemin belirgin özellikleri:

- Solunum sinyalinin torax empedans değişimi metodu ile alınması,
- Ekg ve solunum sinyallerinin birlikte gönderilmesi,
- Alıcı sistemin mikroişlemci tarafından otomatik olarak hastaları takibi,
- Meydana getirilen sistemin tasarımı anlatılan birçok neden dolayısı ile ucuza mal edilmesidir.

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LIST OF ABBREVIATIONS

AM :Amplitude modulation

CCITT:The International Telegraph and Telephone Consultative Comittee

CCU :Critical Care Unit

CMRR :Common Mode Rejection Ratio

CPU :Central Processing Unit

CRT :Cathode Ray Tube

ECG :Electrocardiogram

EEG :Electroencephalogram

FCC :Federal Communications Comittee

FM :Frequency Modulation

IEE :Institute of Electricity and Electronics (U.K.)

MPU :Microprocessing Unit

PLL :Phase Locked Loop

RSGB :Radio Society of Great Britain

VCO :Voltage Controlled Oscillator

CHAPTER 1

INTRODUCTION

1.1 What is Biotelemetry and radio telemetry?:

Biomedical telemetry, or Biotelemetry is a special branch of Bioinstrumentation which provides a means for transmitting physiologic information from men or animals to a recording or data processing station for medical purposes, usually with the aims of minimally encumbering the monitored organism.[1]

The transmission medium may be either a radio link or a line.In the case of a line connection, the term "line telemetry" is used when the subject and station are in different locations.With the exception of some physiologic data transmission and monitoring by telephone lines,biomedical telemetry today mainly uses a radio link between the sites.In this case the term "Radio Telemetry" is used and the described techniques can easily be extrapolated to by wire implementations because the encoding and decoding techniques are similar.[2]

1.2. History:

If we look at the history of biotelemetry, we will see that one of the earliest recorded uses of telemetry for medical purposes occured in 1921. The United States Army Signal Corps used a telemetry system to transmit heart sounds from ships to medical facilities on shore. Later Holter (1949)[2], first used a portable instrument for transmitting physiological data(EEGs and ECGs) by radio.Many other investigations using radio telemetry could be mentioned such as for intracranial pressure, temperature, PH, emg., respiratory ventilation, oxygen analysis of breath and bleeding localisation.However, most of these are for specific research investigations and few have been widely applied.

1.3 Uses of Radio Telemetry:

In clinical setting, biotelemetry can provide for total electrical patient isolation and ambulatory freedom, and is proliferating in dental research. Portable emergency care units now may communicate with hospital base stations with voice and physiologic data from remote emergency situations.Biotelemetry has also permitted physiologic monitoring in many research areas where freedom from restraint and attached wires is important to the study both with animal and human subjects.A broad spectrum of animal species has been monitored by biotelemetry. This includes lizards, snakes, fish, seals, elk, and birds in the wild as well as the more common monkey, dog, cat, rat, and rabbit laboratory animals.Human studies of the physiology of exercise and physical stress, and investigations of fetal and maternal physiology have found freedom of restraint provided by biotelemetry to be of great benefit.[1]

1.4 Biotelemetry Systems:

There are essentially two classes of telemetry systems which can be used for both research and patient care.

a)Implantable[14] systems;These are primarily used for long term measurements in both humans and animals where an external system would be overly cumbersome.For humans an individual is not usually subjected to the trauma of surgery for the sole purpose of implanting the unit , unless its use is necessary for the well being of the patient. An example of such a procedure would be the placement of an intracranial pressure telemetry unit in a hydrocephalic child to help keep the accumulation of cerebrospinal fluid under control . For some animal studies it is desirable to place the telemetry unit within the animal to avoid the possibility of damage caused by normal activities of the animal. An implanable telemetry system offers the following advantages:

1-It eleminates the need for percutaneous leads which can result in irritation and/or infection.

2-By placing the unit within the subject to be studied, it is protected from physical damage.

3-Because it is hidden from view, a pschological factor is removed.

The disadvantages of implantable systems are:

1-Repairs and design changes cannot be made.

2-Severe limitations are placed on the power supply.

3-A packaging material which will protect the electronics for is yet to be found.

b)External systems[14];This second class is composed of external systems which can be placed on a belt, in a shoulder bag, or on the back of the animal.The maximum size of such a system is dictated by the subject which is to be monitored.A human could function normally with a unit occupying a volume on the order of a 100 in^3 and weighing up to 1 kg. while a system intended for a rat would have to be on the order of 10 cc weighing tens of grams.External systems are used primarily for short term tests and monitoring where the inconvenience of telemetry unit is easily tolerated.

External systems have the advantages of;

1-Complex circuits and systems are permissible since space is normally not a problem.

2-Frequent calibration, offset adjustments, and repairs are possible because all components are readily accesible.

3-Protective packaging is usually not necessary since the unit is not subjected to the harsh environment of the body.

4-Power consumption is not a major problem since batteries can easily be replaced or recharged.

5-Surgery is not required before the system can be used.

6-The system can be used more than once.

Some of the disadvantages of external systems are;

1-The leads can be pulled and/or chewed by animals who do not understand the importance of or the need for, such a foreign equipment attached to their bodies.

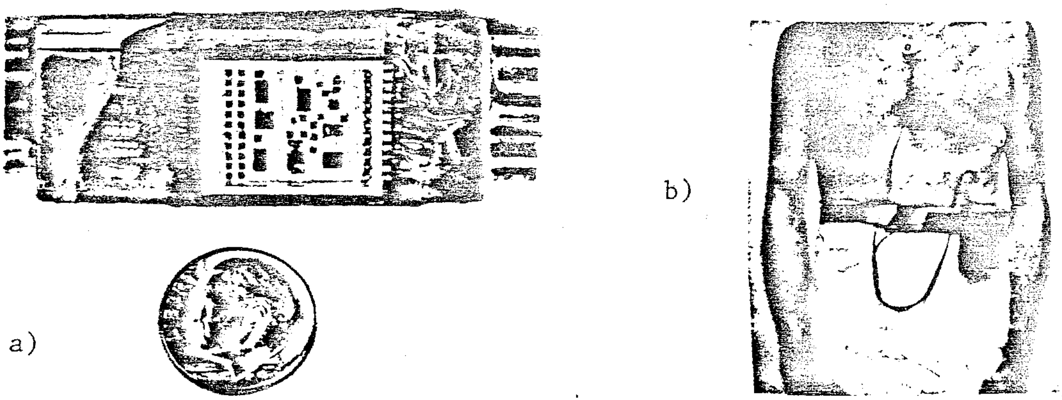
2-The measurement and transmission of some physiological signals, such as changes in heart dimension as measured by a set of ultrasonic crystals, require percutaneous connections which are susceptable to irritation and infection.

3-An interesting problem may be the psychological effect of the unit on a person who feels uneasy or awkward with such a unit on his or her body.

Although there are single channel and multi-channel biotelemetry systems, modern clinical and research telemetry systems are mostly multichannel systems due to the variety of physiologic signals to be transmitted .

These systems generally introduce either a time division multiplex or frequency division multiplex method to achieve multichannel transmission. Since it will be beyond the scope of this thesis, I don't give the discussions on the various available systems, however, a collection of Pulse Amplitude Modulation, Pulse Width Modulation, Pulse Position Modulation and pulse code modulation systems are briefly introduced and a detailed comparison among these systems are carefully examined in chapter three.

Although most frequently used signals in biotelemetry are electrocardiogram (ecg), temperature, respiratory ventilation, mean blood pressure, electromyogram and electroencephalogram signals, for further research, I present the whole collection of physiologic signals from the human body, the electrical characteristics and methods for obtaining these signals.(see appendix A, table II)



a) Implantable unit (Coin is shown for comparison)
b) external unit.

Fig.1.Implantable and external Biotelemetry systems.

CHAPTER 2

SPECIFICATIONS OF THE BIOTELEMETRY SYSTEM TO BE PRESENTED IN THIS THESIS

2.1 Generalized Radio Telemetry System:

A radio telemetry system in most general way can be described as shown in figure 2.

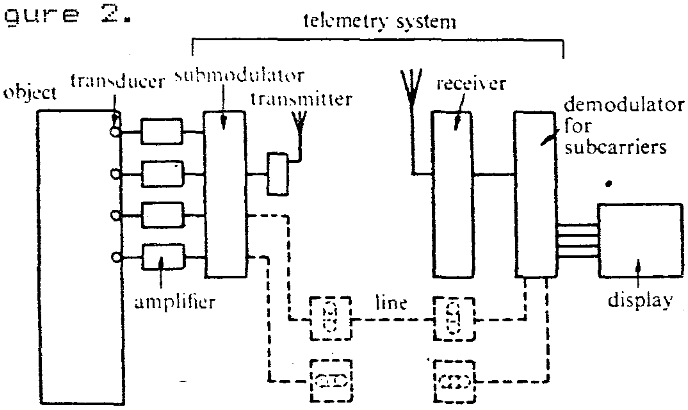


Fig.2. Block diagram of the generilized Biotelemetry System.

Beginning from this simple block diagram, I am going to give the specifications of the system presented in this thesis. The design philosophy and the implementation will be explained in the next chapter.

After a heart attack, the patient is normally placed in a coronary care unit for a few days.Unfortunately the CCU is very expensive and has a limited number of beds.Therefore the patient is only extensively monitored for a few days until he or she is moved to a room where there is little or no monitoring[4]. The cardiologist may gather ECGs several times a day while the patient is in the hospital in an attempt to determine exactly what is wrong with the heart. During this period or after an operation, there comes the use of the Biotelemetry monitoring.

2.2 System specifications :

Although there are several physiological signals, that can be monitored, the ECG and respiration signals are chosen for telemetry monitoring, since temperature for a " step down unit " patient can be recorded twice a day, by a nurse, and there are very rare occasions that the patient's blood pressure or flow without disturbing the normal heart and respiration rates. In those cases the patient will feel the discomfort and/or a pain, and will call a nurse for care.

Monitoring the ECG and respiration rate has several applications at other fields such as exercise ECG examination and sports physiology where the subject can be monitored without limiting his capabilities of action.

For monitoring the ECG, in Biotelemetry systems, instead of 12 lead standard connection, the 3 lead augmented configuration is used to optimize the information obtained versus simplicity.

For respiration signal, there are two approaches in recent devices. One, picks up the respiration signal by using a thermistor placed close to the nose of the patient. As the patient breathes, the exhaled air causes a resistance change in the thermistor and therefore the respiration rate is detected.

The second method is to pick up the transthoracic impedance change to high frequency current due to the changes in the dimensions of thorax as the patient breathes.

To give the least disturbance to the patient, while 3 electrodes are connected to pick up the ECG, I found the most convenient way to obtain the respiration would be to use the transthoracic impedance change method, since no extra transducers needed.

In the following page the complete block diagram of both the transmitter and receiver is shown. (Note Fig.3)

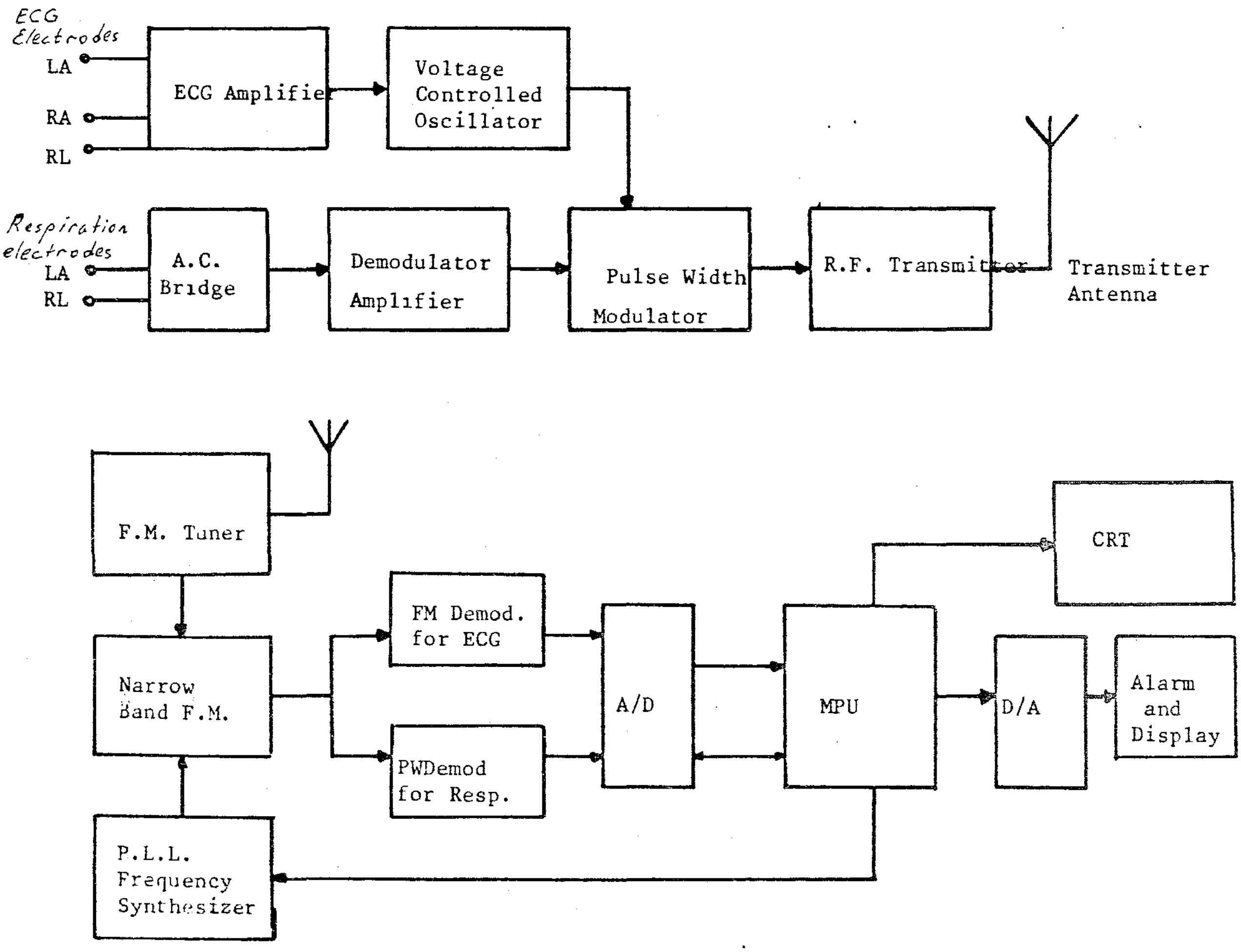


Fig.3 Complete block diagram of the designed system

The ECG is then amplified by an A.C. coupled amplifier having a gain of 750, CMMR of 35 decibels, very high input impedance(in the order of 100 M ohms), and a frequency response of 0.6-90 Hz.

The respiration amplifier is preceeded by an ac bridge, amplifier and demodulator, and a filter to detect the impedance change.The frequency response of this amplifier is 0.07-0.7Hz, gain is approximately 470 and the sensitivity range is +/-0.5 ohms with a base resistance 500-800 ohms.

The ECG signal is then FM modulated where the center frequency is 1.2kHz and maximum swing is +600, -200 Hz, due to the voltage levels of the ECG. This waveform is then Pulse Width Modulated by the respiration signal that varies the pulse width between 0.6msec and 0.4 msec.

The composite signal is then level shifted and sent to the RF FM modulator-transmitter stage.

The composite signal modulates a 35 MHz crystal oscillator, and this frequency is doubled twice to obtain a 140 MHz operating frequency. This signal is then amplified and then fed to the transmitter antenna. There is a second order low pass filter on the antenna side to prevent the transmission of higher order harmonics.

The receiver front end is a down converter block from 140 MHz to 10.7 MHz , and the second block is a narrowband FM demodulator with intermediate frequency of 455kHz. The center frequency of this narrowband FM receiver is controlled by a P.L.L. frequency synthesizer. The demodulated signal is then fed to a demodulator block that can demodulate FM and PWM signals to recover the ECG and respiration signals. The demodulated signals are in the order of several hundred millivolts and then sent to an analog to digital block in order that the microprocessor unit can perform the following tasks;

-if the channel is set and the number of active channels are specified with their alarm limits, the processor scans the channels one by one in sequence.

-at the end of each cycle of the recovered signal per channel, the MPU calculates the rate and compares it with the set alarm levels.

-if the alarm limits are exceeded or the P.L.L. can not lock to the patient the MPU activates the alarm circuitry, and displays the channel that caused the alarm condition.

-if everything is smooth, displays the channels one by one in 15 sec. intervals.

The major points of the designed system making it special are;

-The transthoracic impedance method for detecting the respiration rate.

-Scanning the patients with the frequency synthesizer.

-The microprocessor system that calculates and compares all the alarm conditions and enabling the system for use with one single CRT display making the system cost efficient.

CHAPTER 3

THEORETHICAL CONSIDERATIONS FOR THE PROPOSED BIOTELEMETRY SYSTEM AND DESIGN IMPLEMENTATION

3.1.1 The basic theory of the Electrocardiogram and the ECG amplifier:

The biopotentials generated by the muscles of the heart result in the electrocardiogram, abbreviated ECG. The heart is divided into four chambers.The two upper chambers , the left and right atria, are synchronised to act together.[5] Similarly the two lower chambers, the ventricles, operate together. For the cardiovascular system to function properly, both the atria and the ventricles must operate in a proper time relationship.A cardiac cycle originates in the sinus node which is high in the right atrium.Pacemaker cells in the sinus node initiate a wave of cellular depolarization that moves across both atria, which results in the contraction of the atria and filling of the ventricles with blood. This wave of excitation penetrates the ventricles via the atrioventricular node. Here a delay is introduced before the depolarization wave is passed through the Bundle of His, branches and Purkinje fibers to the ventricular cardiac muscle.During sinus depolarization both the left and right bundle branches will be activated simultaneously, producing a narrow QRS complex of approximately 60 msecs.During the T wave the ventricles repolarize, ready for the next activation sequence.

Some normal values for amplitudes and durations of important ECG parameters are as follows:

Amplitude
P Wave 0.25 mV
R Wave 1.60 mV
Q Wave 25% of R wave
T Wave 0.1 to 0.5 mV

Duration
P-R interval 0.12 to 0.20 sec
Q-T interval 0.35 to 0.44 sec
S-T segment 0.05 to 0.15 sec
P Wave interval 0.11 sec
QRS interval 0.09 sec

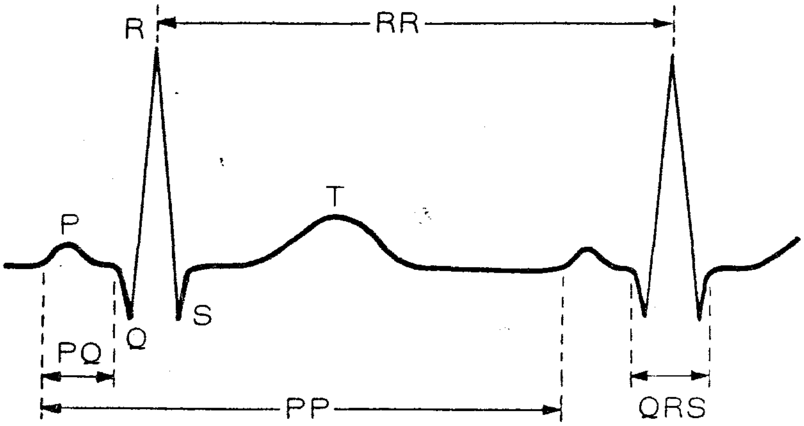


Fig.4 Normal ECG waveform.

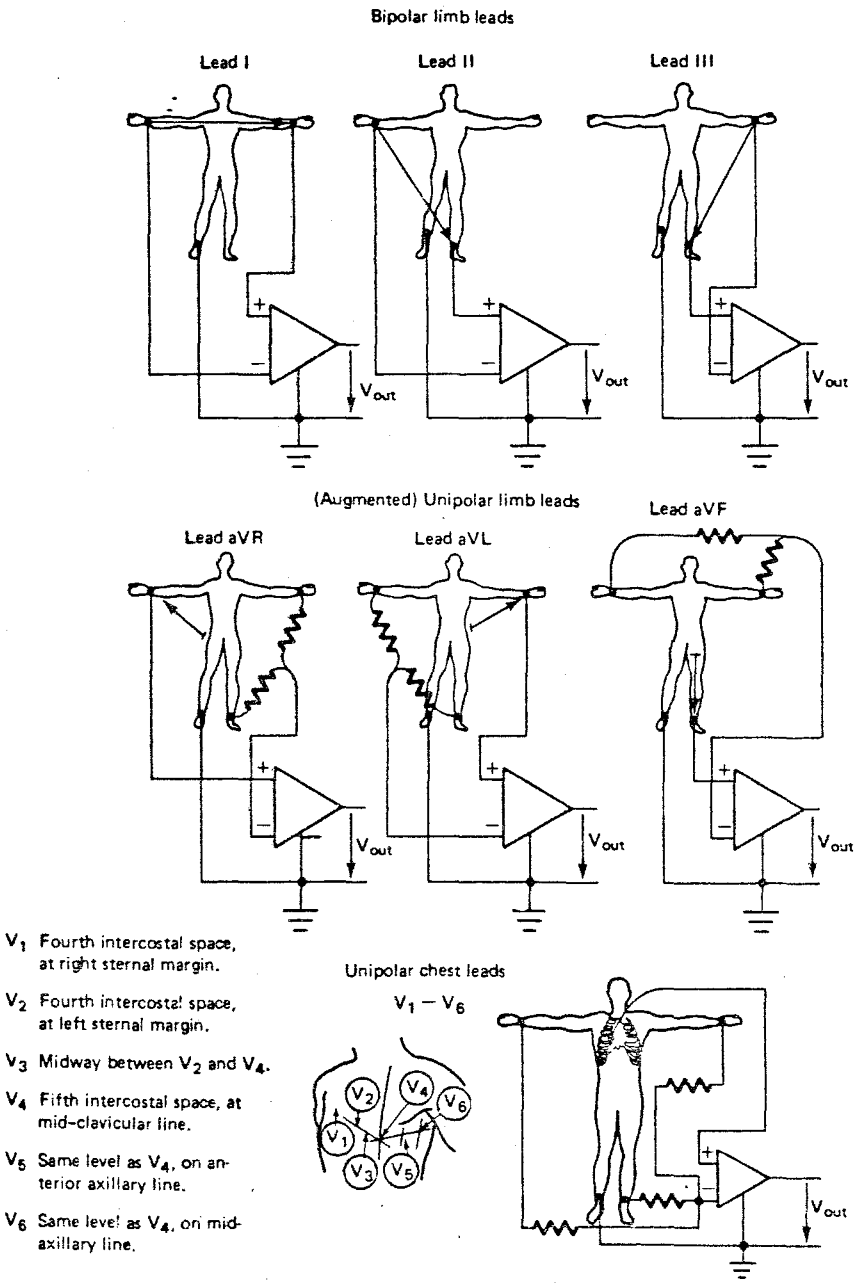
3.1.2 Electrodes:

Although there are suction and plate types of electrodes available to pick up the ECG signal for the purpose of Biotelemetry and clinical practice, the disposable, self adhesive type of surface electrodes are best suited. I used the Ag-AgCl type of these electrodes since they were available on the market and not very expensive.

3.1.3 Lead configuration and electrode positioning:

The three bipolar limb leads first introduced by Eindhoven,[5] shown in the top row of the figure 5, are as follows:

Lead I :Left arm and right arm
Lead II :Left leg and right arm
lead III:Left leg and left arm



V_1 Fourth intercostal space, at right sternal margin.

V_2 Fourth intercostal space, at left sternal margin.

V_3 Midway between V_2 and V_4.

V_4 Fifth intercostal space, at mid-clavicular line.

V_5 Same level as V_4, on anterior axillary line.

V_6 Same level as V_4, on mid-axillary line.

Fig.5 Standard ECG Lead configurations.

These three leads are bipolar because for each lead the ECG is recorded from two electrodes and the third electrode is not connected.

For unipolar leads, the ECG is recorded between a single exploratory electrode and the central terminal, which has a potential corresponding to the center of the body.

For the Unipolar chest leads, a single chest electrode is sequentially placed on each of the six predesignated points on the chest. These chest positions are called the precordial unipolar leads and are designated V1 through V6.

The most widely used modification for ongoing ECG monitoring is the modified chest lead I (MCL1) also called the Mariotte lead, named after its inventor. This lead system simulates the V1 position with electrode placement as follows; positive electrode, fourth intercostal space, right sternal border; negative electrode just below the outer portion of the left clavicle, with ground just about anywhere, but usually below the right clavicle, and a region where muscular activity is low.

However since we design the system to pick up the respiration, by using the same electrode set, the optimum positioning of the electrodes is shown on Fig. 6.

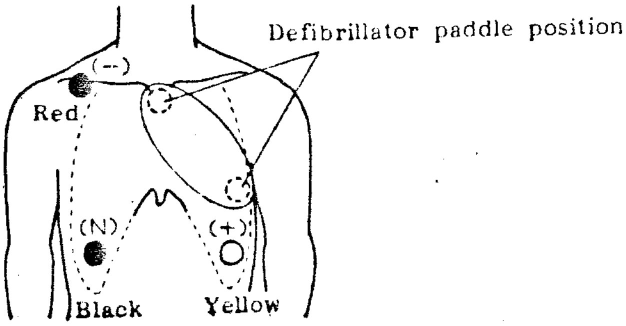


Fig.6 Optimum electrode positioning for picking up both the respiration and the ECG signals.

For Biotelemetry MCL1 is the most suitable lead configuration.However including the probability of applying a defibrillator during monitoring, the leads are connected as shown in figure 6.

3.1.4 ECG Amplifier:

As a standard in ECG amplifiers, I used a differential input three op-amp instrumentation amplifier configuration to achieve a high common mode rejection,[9] high input impedance, and comperatively high gain stage. In order to prevent saturation of the front stage, because of the 250-300 mV d.c. offset due to the electrode half cell potential, the gain of the first stage is limited to 4.5/300mV=15 .The gain of the both stages can be expressed as follows;

$$A_v = \frac{R_{f_2}}{R_2} \cdot \left(1 + \frac{2 R_{f_1}}{R_1}\right)$$

Since it may be possible to apply the defibrillator to the patient while the amplifier is also being connected , the amplifier is preceeded by a protection circuitry consisting of two Zener diodes, resistors and capacitors.Under worst case conditions the diodes clamp the inputs of the op-amps to 3.9V DC level, the resistors limit the current to the diodes for 200 mW power dissipation and the capacitors filter the transients and drift. This circuitry protects the inputs up to 4 kV.After that the diodes are burned out and may be the capacitors and op-amps are destroyed.The second and third stages are ac coupled stages to get rid of the drift and offset problems and actually these are the stages that set the frequency response of the amplifier.

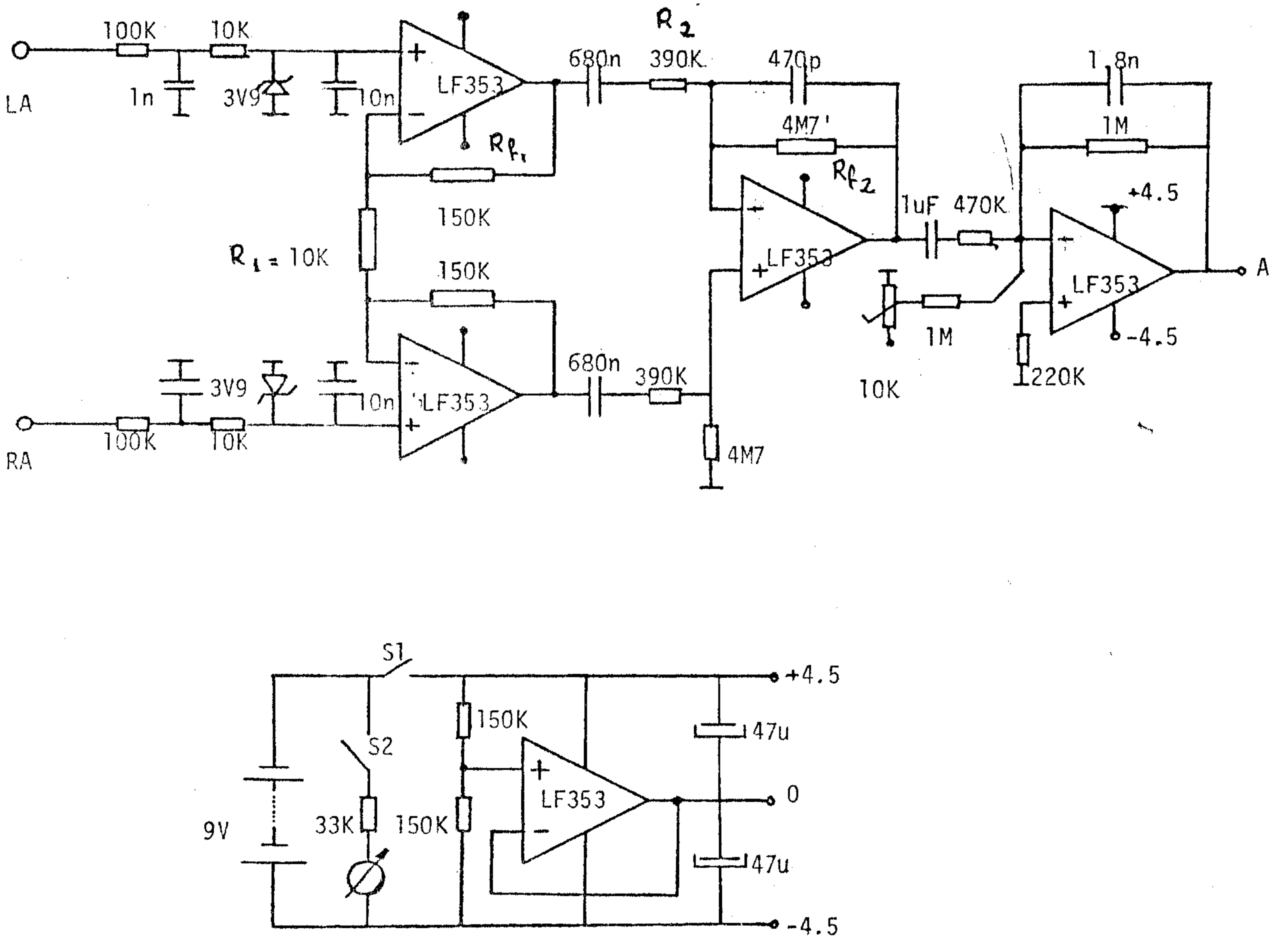


Fig.7 ECG Amplifier and the Power supply

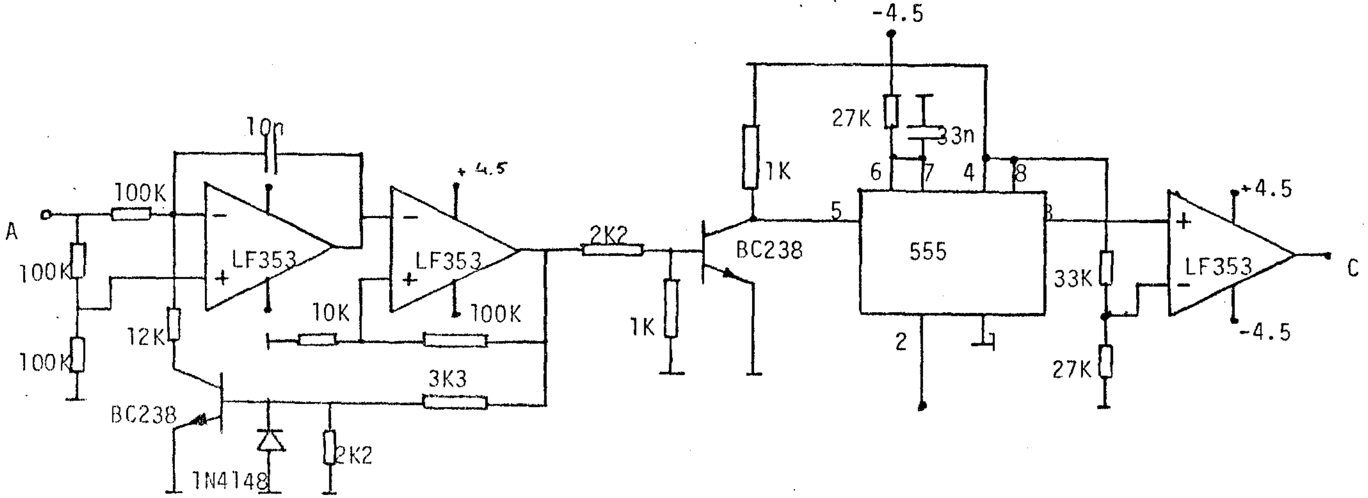


Fig.8 FM-PWM Subcarrier modulator circuit scematic.

With the values shown in the figure 7 , the lower cut off frequency is set by the serial capacitor and resistors to 0.6 Hz and the higher cut off frequency is set by the feedback capacitors and resistors to approximately 90 Hz.The common mode rejection ratio depends upon how well the indicated resistors are matched to eachother, and in my experimental setup the CMRR is approximately 35 dB as tested with the ECG Calibrator of Neurodyne.

3.1.5 F.M. Subcarrier Modulator:

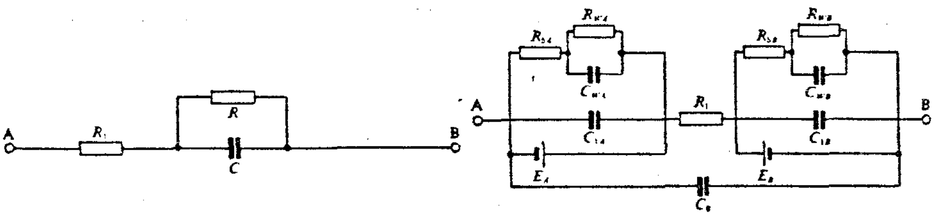
The output of the ECG amplifier is in the order of a couple hundred mVs.This signal is used to FM modulate the ECG subcarrier.The subcarrier frequency shouldn't be high since we don't want to use expensive, high gain bandwidth product components.On the other hand not to cause the sideband foldover distortion, the carrier frequency should be kept high enough.In order to easily and accurately reconstruct the desired signal, the frequency of the pulses should be at least five to ten times the upper frequency limit of the physiological signal being monitored.(4 I found that the optimum center frequency is a little bit higher than 1 kHz namely 1.2 to 1.5 Khz.The two op-amp circuit forms a good voltage controlled oscillator with minimum number of components.The first op-amp is an integrator which is controlled by the second op-amp that acts as a voltage comparator.Since this stage is followed by a pulse width modulator, the duty cycle is not selected as 50% to be competible with the next stage.The frequency of the VCO varies with a constant of approximately 1.4Hz/mV.

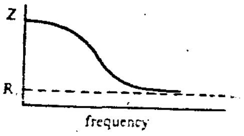
3.2.1 Basic theory of the electrical impedance measurements:

When an electrode is connected to a biological tissue, because of the double layer at the electrode interface a capacitive effect can be observed.[1] On the other hand there is a finite contact area specifying a contact resistance of the interface.The tissue also has a certain resistivity per cm. and a capacitance due to the time varying electrical fields.

If we consider these effects it is possible to draw the electrical equivalent circuit of the system.The true ohmic resistance of the biological specimen is taken to be the constant value of impedance which is approached as the frequency is increased.At higher frequencies, the reactance of C will become significant , and theorethically it will eventually effectively short circuit the electrodes.(Note Fig 9)

In the measurement of the transthoracic impedance changes accompanying respiration, the change in impedance is produced by a resistive change, the magnitude of which is independent of frequency over the range of 50-600kHz.





Equivalent electrical circuit of electrodes in contact with biological material

R_1 = true ohmic resistance of the biological material

C_0 = capacitance formed by the electrodes and the dielectric properties of the biological material

C_{1A}, C_{1B} = capacitance of the double layer at electrodes A and B, respectively

R_{WA}, C_{WA}, R_{WB}, C_{WB} = parallel equivalents of the Warburg impedance at each electrode

R_{sA}, R_{sB} = pure resistances

E_A, E_B = halfcell potential at each electrode

R_{sA}, R_{WA}, C_{WB} and R_{sB}, R_{WB}, C_{WB} represent impedances associated with the electrolytic process

Fig.9 Electrical equivalent circuit of bioelectrodes.[2]

3.2.2 Practical measurement system:

The principle of the operation is to inject a constant, high frequency current to the tissue and demodulate the AM modulated signal due to the impedance change[2].(Fig 10)

In our system, the oscillator provides a 100 kHz, 20 V peak to peak signal to the ac respiration bridge.The current to the bridge is limited with a 10K ohm resistor and a series capacitor prevents the application of DC voltages to the tissue.

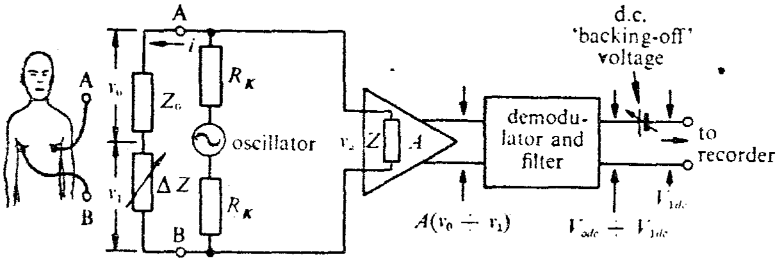


Fig.10 Two terminal method for respiration detection.

The balance resistors are chosen to allow a reasonably wide range of base chest impedances, since it can vary from one person to another depending upon the type of the tissue.With the values given, the amplifier can operate with base resistance range from 500 to 850 ohms with the sensitivity of 0.5 ohms.The output of the bridge is an AM modulated signal and demodulated by a rectifier and a filter. The following ac coupled stages employ a gain of 500 in the frequency band of 0.07-0.7Hz.

The output of this amplifier is used to Pulse Width Modulate the

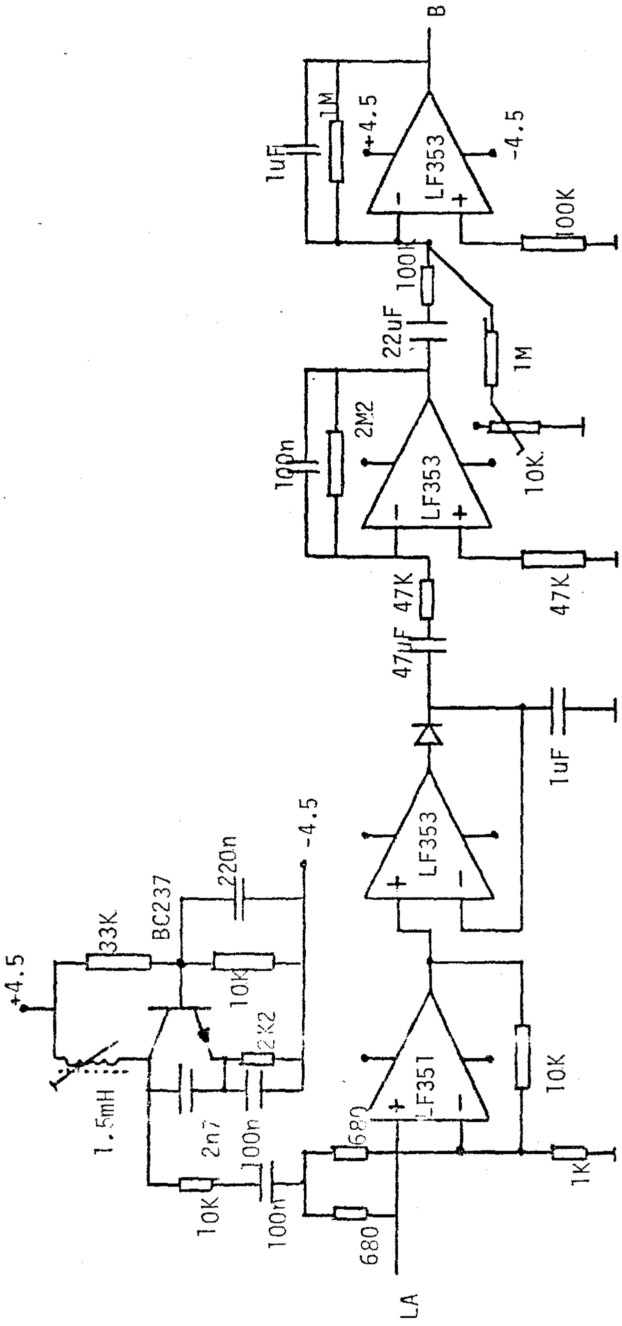


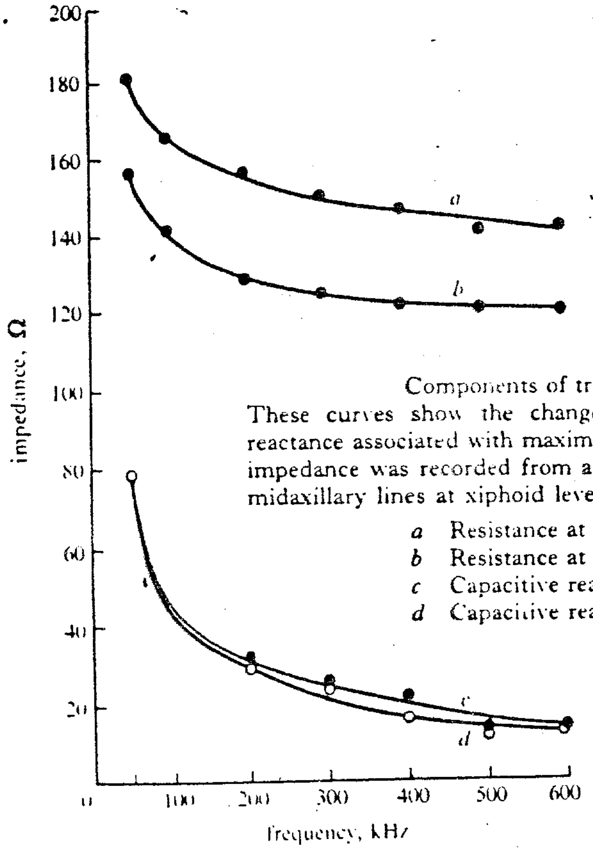
Fig.11 Circuit Diagram of the respiration signal section

Table 1. *Values of tissue specific resistance measured at body temperature except where noted*

	Human			Dog		
Material	Specific resistance	Frequency	Reference	Specific resistance	Frequency	Reference
	Ω cm	kHz		Ω cm	kHz	
Muscle (skeletal)	240 (longitudinal)	0·02–5	BVD	760	10	SK
	675 (transverse)			600–1200	10	S
Muscle (heart)	—	—	—	456/600	100/10	K/SK
	—	+	—	700–900	10	S
Lung	—	—	—	1345–2100	100	K
	—	—	—	800–1200/950	10/10	SL/SK
Bone	16000	EKG Spectrum	L (temperature not specified)	—	—	—
CSF	64·6	1–30	R (24·5 °C)	—	—	—
Spleen	—	—	—	885	Inductorium	G
Kidney	—	—	—	600	100	K
Liver	—	—	—	600/685/700–850	100/10/10	K/SK/S
Fat	—	—	—	1000–3000	100	K
Blood	154	120	M (36·3 °C)	155 (41 % hematocrit)	100	K

References

SK: Schwan and Kay, 1956
BVD: Burger and Van Dongen, 1960
S: Schwan, 1955
K: Kinnen *et al.*, 1964
SL: Schwan and Li, 1953
G: Galeotti, 1902
M: Molnar *et al.*, 1953
R: Radvan-Ziemnowicz *et al.*, 1964
L: Lepeschkin, 1951



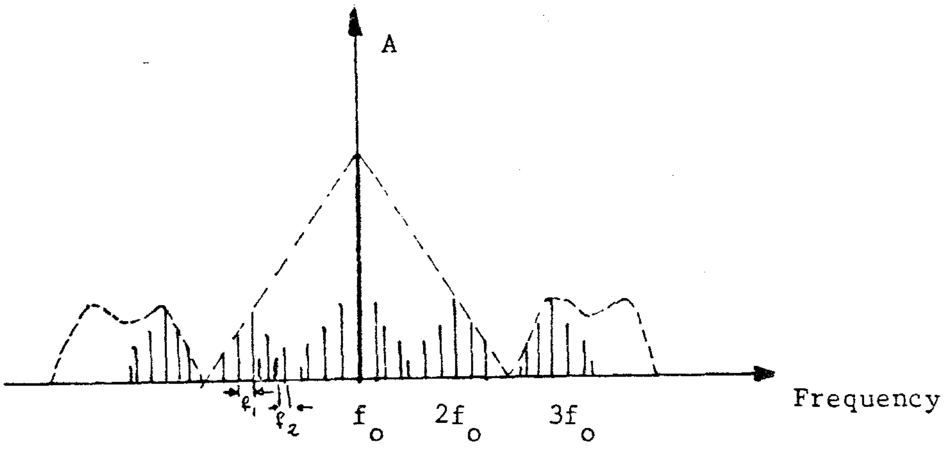
Components of transthoracic impedance against frequency
These curves show the change in transthoracic resistance and capacitive reactance associated with maximum inspiration and maximum expiration. The impedance was recorded from a pair of electrodes placed bilaterally along the midaxillary lines at xiphoid level.

a Resistance at maximum inspiration
b Resistance at maximum expiration
c Capacitive reactance at maximum inspiration
d Capacitive reactance at maximum expiration

Fig.12 Components of transthoracic impedance vs. frequency clock generated by the subcarrier oscillator of the ECG.

With this arrangement we have the minimum power and space requirement compared with time division multiplex frequency division multiplex systems or pulse code modulation systems

The signal to noise ratio of this type of modulation is better than pulse height modulation systems and the required bandwidth is approximately 2 times the center frequency.See Fig. 13



f_1 is the min. freq. of the ECG subcarrier

f_2 is the min. width of the respiration subcarrier

Fig.13.Frequency spectra of the subcarrier signal.

3.3.1 The RF transmittion system:

While designing the transmitter stage,[2] the following points are taken into consideration;

1-Maximum simplicity and relaibility

2-Minimum power consumption

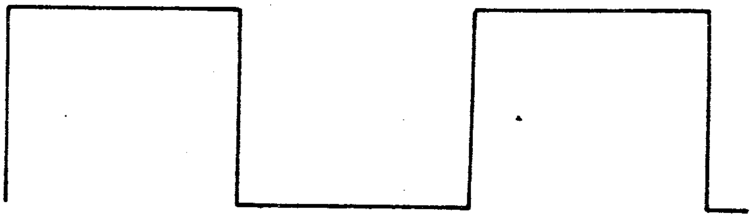
3-Optimum adaptation to International standards

The choice of the transmitter frequency for implantable units may be dictated by the region of the body in which it is to be placed, since the attenuation factor in the body increases with increasing frequency.

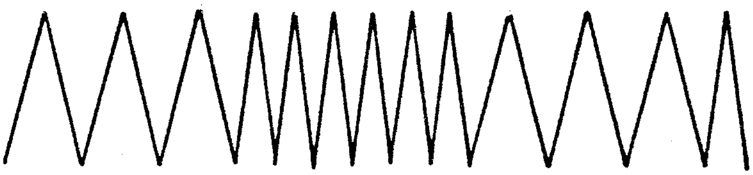
The above discussion would tend to suggest that a lower frequency system would be better , however for a fixed amplitude radiation source, the antenna gain increases due to the increase in the effective length, therefore the radiation distance is increased.

Since our power resources at the transmitter side are limited, we can not use a double side band AM modulation with carrier.The noise susceptibility of that kind of modulation is also rather poor compared with other modulation systems.SSB modulation will be more efficient for power supply considerations however would require more space, also both the transmitter and the receiver would be more complicated.

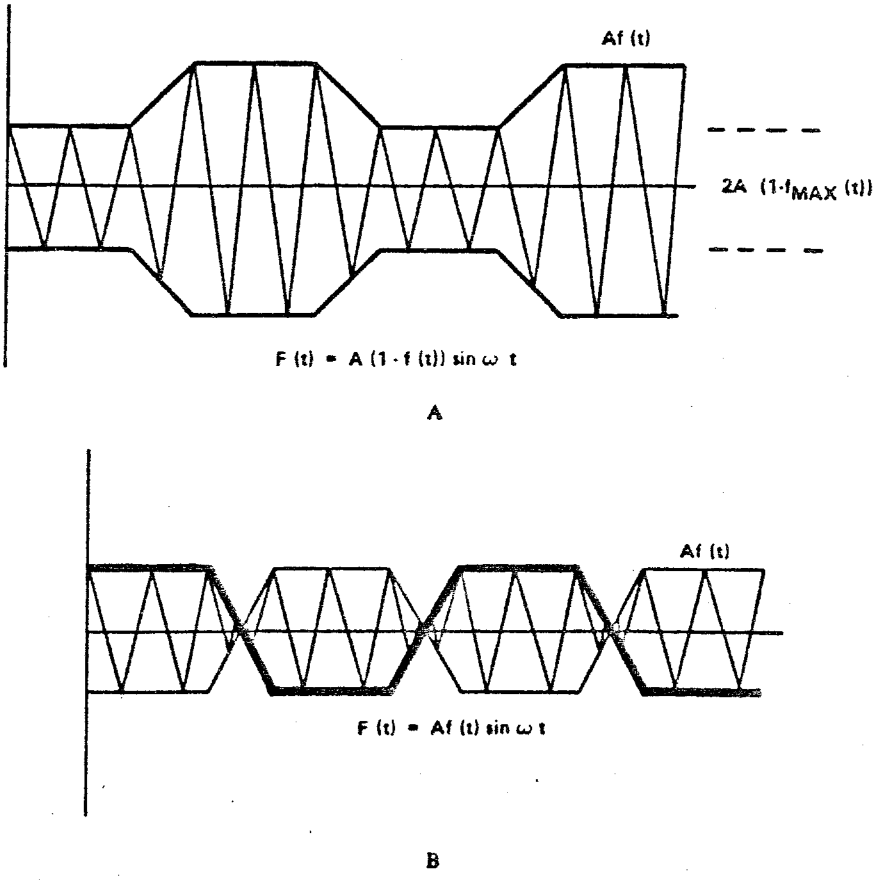
Unfortunately there are no international frequency for the allocation of Biomedical telemetry .The United states has a different set of regulations, accepted by FCC, and the European hemisphere has different allocations set by CCITT.In our country there are still some arguments going on and no channel allocations are set untill now.However it is very possible that for compatibility with the European countries,which we share the same standards for communications (CCITT Standards), will be accepted in the future.For this reason I concentrated on 40 MHz , 151 MHz , and 470 MHz bands on the following table.With 40 MHz band, one has the bulky dimensions of the antenna and the space problems with the tuned circuit inductors on the transmitter board.It was also impossible for me to design the transmitter and receiver stages at 470 MHz band, since I don't have neither the experience nor the special components that the design requires at this band.



MODULATING SIGNAL



FREQUENCY MODULATION



Waveform for conventional AM (A) and suppressed carrier AM signal (B).

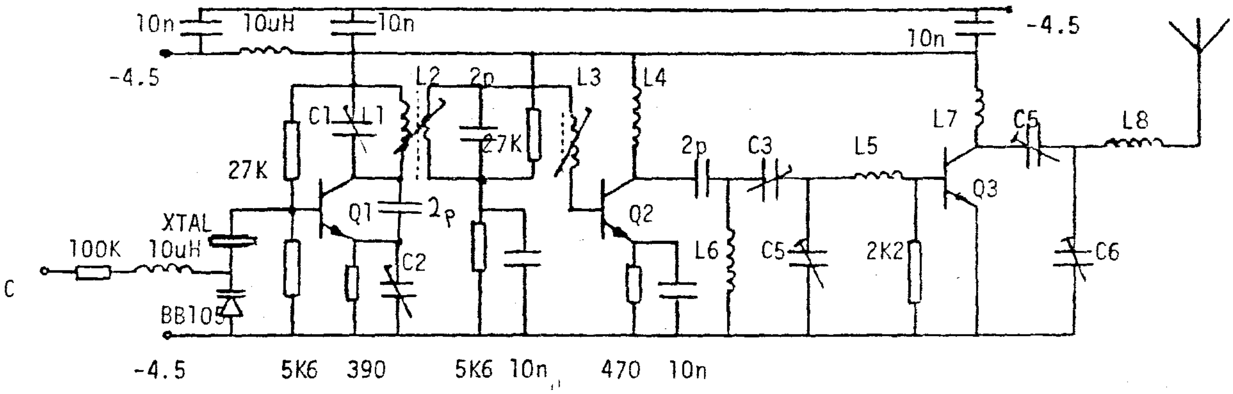
Fig.14 Comparison of the different RF carrier signals.

In the following page, the two versions of the transmitter stage in shown.

In the old version fig.15 a, after the doubler stages, there is an output stage. With this configuration the range is increased but the power consumption is increased 3 to 5 times.

I presented it here, for the cases doesn't have a limited power source.

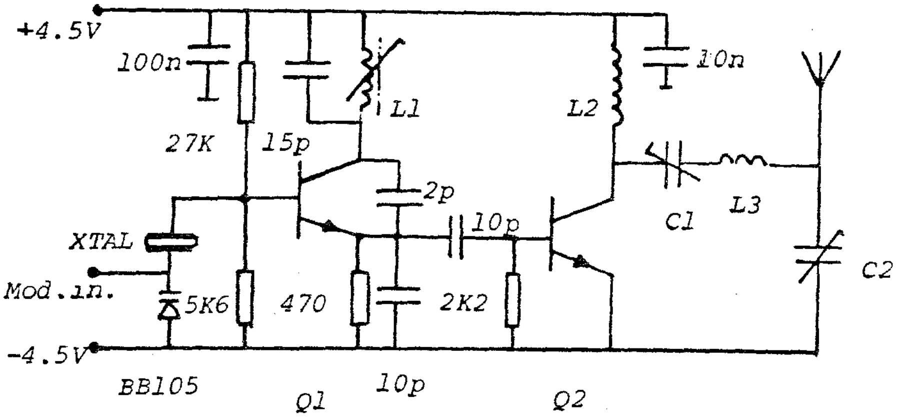
The new version fig.15 b, has less power consumption so operates in a short range, just for demonstration.



C2,C6-20-40pF
C1,C3,C4,C5-5-30pF
L1-550nH L5-100nH
L2-250nH L6-300nH
L3-500nH L7-60nH
L4-300nH L8-40nH

Q1,Q2,Q3-BF240
For details of inductor construction see appendix.

a) The former version with high power consumption



Q1,Q2 BF240
C1,C2 4-25pF
L1 1.7uH . L2 450nH , L3 180nH

b) The revised version

Fig. 15 Circuit diagram of the transmitter

So we are left with the 150 MHz band for experimenting.However working on any of these three locations, require a special permission from TGM, a special government agency responsible from the wireless communication systems.

Advantages of the 40 MHz band;

a)Reduced capacitive coupling

b)Less reflection from buildings and other obstacles.

Advantages of the 160 MHz band;

a)Easier aerial matching

b)Smaller in size

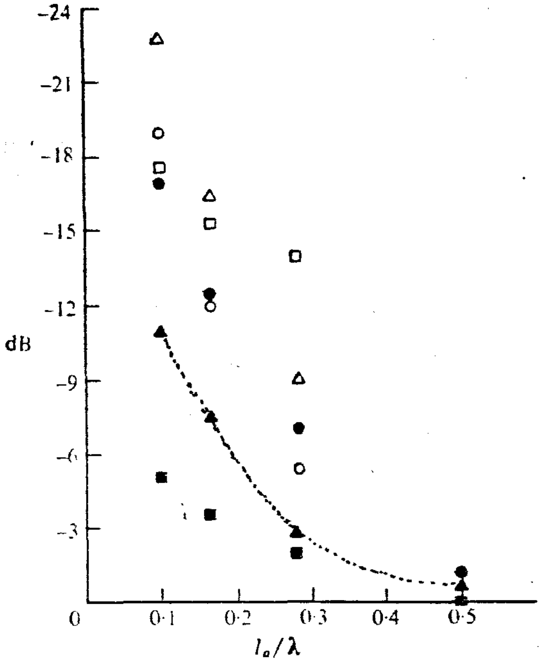
It is obvious that, in order to have a stable frequency, one has to use a crystal controlled oscillator.Therefore I used a 35.5 MHz. crystal for oscillation and used two frequency doublers to obtain 142 MHz. carrier.(This is less than 151 MHz. however since the techniques used are the same and I only intend to put together a demonstration set up, this is acceptable)

This kind of circuitry is also more stable since the parasitic elements are less effective at lower frequencies.The design of the doubler stages are made by using the large signal parameters of the transistors since the voltage levels are in hundreds of mV or in volts.The output stage delivers approximately 50mW to the 50 ohm antenna, and this power is sufficient at the operation frequency for use in the same building.The design details and the inductor specifications are available in appendix.

3.3.2 Aerial

The aerial presents several particular problems.It is short with respect to the wavelength, it is close to an absorbing or re emitting medium(the human Body), and the orientation is varying not only in time but also from case to case.See Fig16

If we use one of the many formulas for field strength E at the receiver aerial;



Aerial attenuation dependent on ratio between aerial length l_a and radio carrier length λ for aerial coupling to a large and small transmitter

△ portable front: 35 MHz
○ portable side: 35 MHz
□ pocket: 35 MHz
▲ portable front: 150 MHz
● portable side: 150 MHz
■ pocket: 150 MHz

Fig.16.Effect of aerial length and frequency on attenuation.

3.4.1 Transmitter power supply:

Because of the structure of the instrumentation and the respiration amplifier stages, we have to use split supply for the circuitry. Since the difference current drawn from positive and negative supplies is very small, we used the parallel regulator circuitry, with one op-amp, as shown in fig.7. This circuitry has the advantages of simplicity and symmetry.The regulator part consumes very little energy, causes no voltage drops, and the battery power limits the operation only. The battery can either be a long life 9V mercury cell, or a rechargable NiCad one.

3.5.1 Receiver FM tuner:

The receiver front end is a down converter from 140 MHz. to 10.7 MHz. which consists of an RF preamplifier, mixer, an oscillator with automatic frequency control, and an IF amplifier.The design is achieved by using the small signal y parameter equivalent technique.The input sensitivity is approximately 1 microvolt/meter. Since 10.7 MHz is the standard IF frequeny of the commercial FM receivers it was easy to find parts and the narrowband FM receiver IC was designed for the 10.7 MHz input. Since the bandwidth requirement of each patient is approximately 2.5 kHz , and they are 10 kHz apart from each other it is obvious that I had to use a Narrow Band FM demodulator.The IF frequency of the narrow band FM receiver is 455 kHz, and has a scan control output for microprocessor scanner applications. In order to get the required frequency accuracy and stability the most suitable way is to use a digital frequency synthesizer for scanning the patients.The frequency synthesizer consists of a phase locked loop, a VCO with a center freq. of 10.245 MHz and a programmable divider section that is able to divide the vco freq. by 1000 to 1070 for comparison with the 10 kHz referance signal, obtained from a 2 MHz referance oscillator.The active low pass filter is chosen for better DC gain of the PLL. For simplicity and for the availibility of the parts, I used the Integrated circuits shown on the circuit diagram of the demonstration system.

3.6.1 ECG Demodulation Section:

The audio signal obtained from the NBFM receiver is first

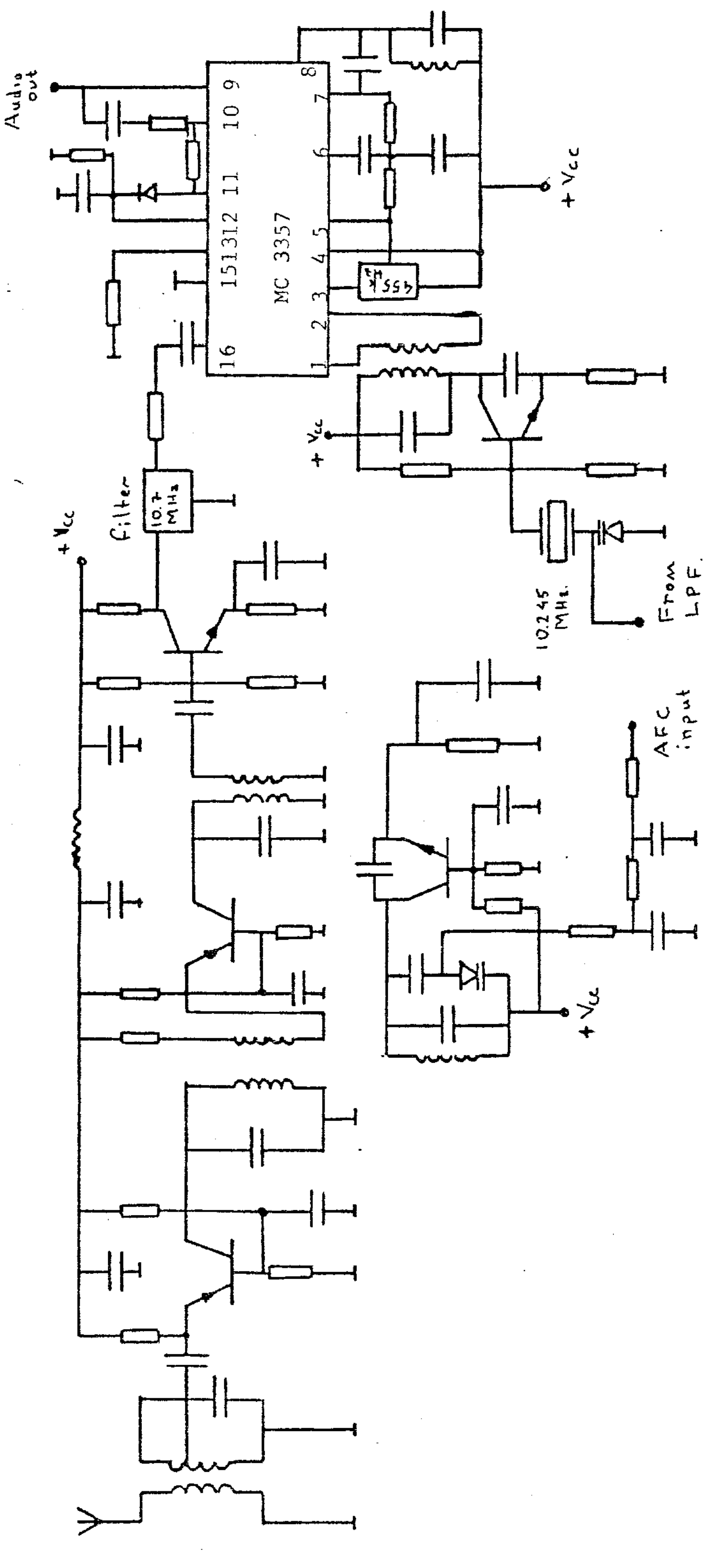


Fig.17 Circuit Diagram of the FM Receiver

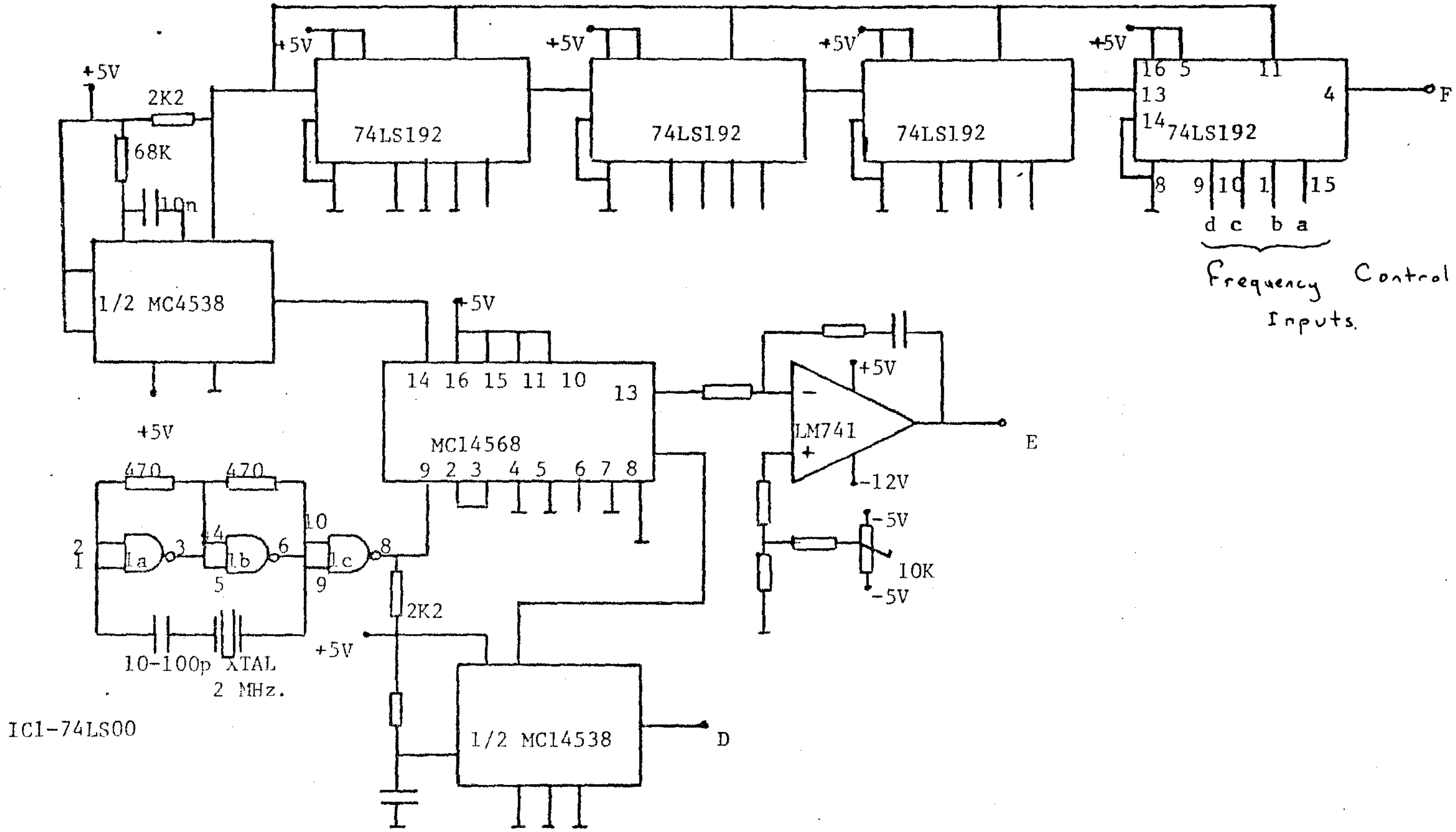


Fig.18 Circuit Diagram of the PLL freq. synthesizer

amplified and filtered and then fed to the voltage comparator to reconstruct the square wave .Then this signal is inverted end level shifted to be connected to the PLL demodulator.The Phase locked loop used here is a single chip PLL, with the center frequency of vco is set by the external resistor and capacitor, to 1.2 kHz, and the low pass filter of the loop is just a simple passive filter. PLL demodulator output is the original ECG requiring a little bit amplification and filtering At point B'. Therefore a one stage amplifeier with filter is cascaded to the PLL with gain 10 and cut off frequency of 100 Hz.

3.7.1 Respiration demodulation section:

In order to demodulate the PWM signal, a capacitor is charged with a constant current source and the discharge is controlled by a switch according to the input information. The peaks of the voltage of the capacitor are detected, filtered and amplified to reconstruct the respiration signal at point C'. This waveform is only useful for respiration rate and apnea monitoring but not calibrated for respiratory measurements.

3.8.1 MPU control section:

The function of this block is to lock to the patients one by one,to convert the incoming signals to digital form for processing, storage and displaying of the signals. For diagnosis of an ECG signal, 100 Hz bandwith is the minimum requirement[4].In order to collect reasonable number of data for reconstruction, if the Nyquist rate is chosen for sampling,this means 200 bytes per second is used. For diagnosis purposes, at least ten to fifteen consistent cycles must be displayed. Therefore for each visual

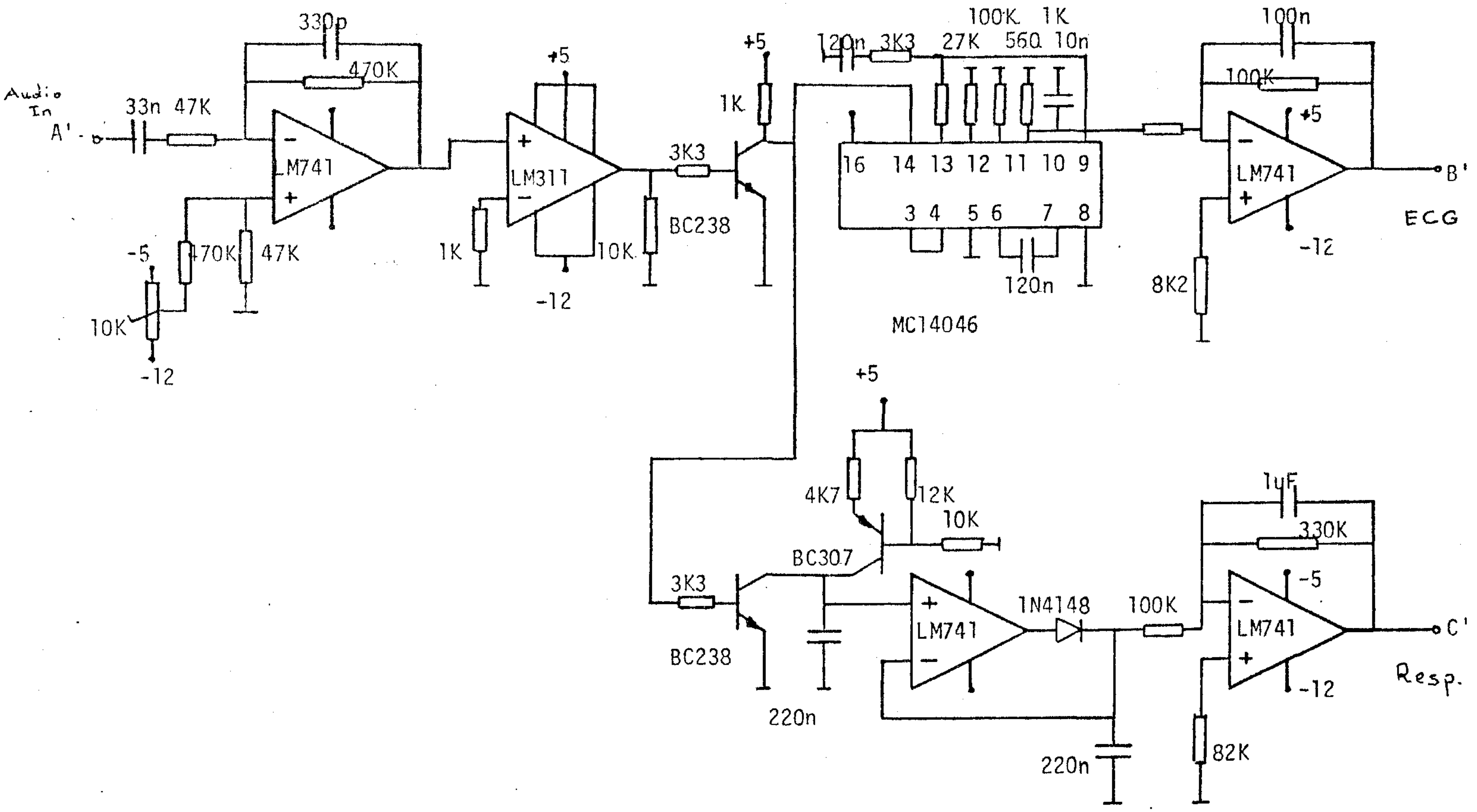


Fig.19 Circuit Diagram of the Receiver, demodulator

ECG strip, 15*200=3Kbytes of memory is required. A similar discussion for respiration will give 0.1Hz*2=0.2 Bytes per second,0.2*15=3 bytes per respiration strip.(A strip is defined as the cycles of signal displayed on the screen at the end of each scanning period.)

Since one may require to display the waveforms on some other analog device, an analog output channel must be available for convenience. Therefore the microprocessor section consists of a two channel 8 bits A/D converter chip, 16 Kbytes of memory, one 8 bit D/A converter, two parallel ports, and a CPU.The MPU is able to input the patient sequence, alarm limits, and other input commands and data.Via a lock detect logic circuitry, the MPU detects a channel is set. Since the time constant of the low pass filter approximately 5msec the oscillator locks to the selected patient. The MPU sets the A/D for ECG conversion and stores the result into that patient's ram area . Then switches the multiplexer of the A/D for Respiration signal conversion, converts the data and stores the result to that patient's area. If one cycle is completed, calculates the period and compares the result with the set alarm limits, and acts accordingly. Then gets a new channel and repeats the same procedure. If it is required to have a replay of the last 15 seconds records, the MPU uses the D/A for generation of the analog signal.

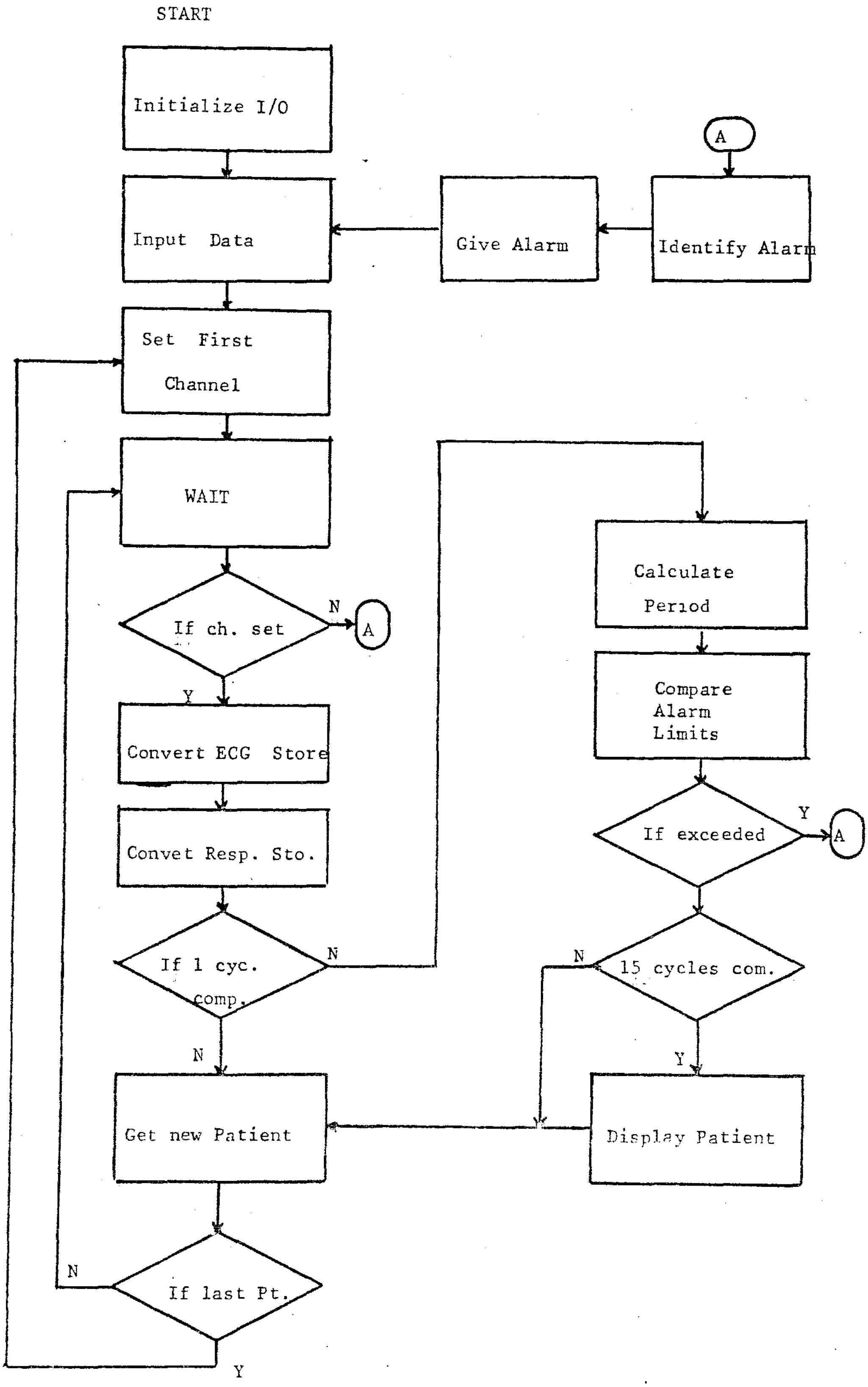


Fig.20 Flowchart of the main program

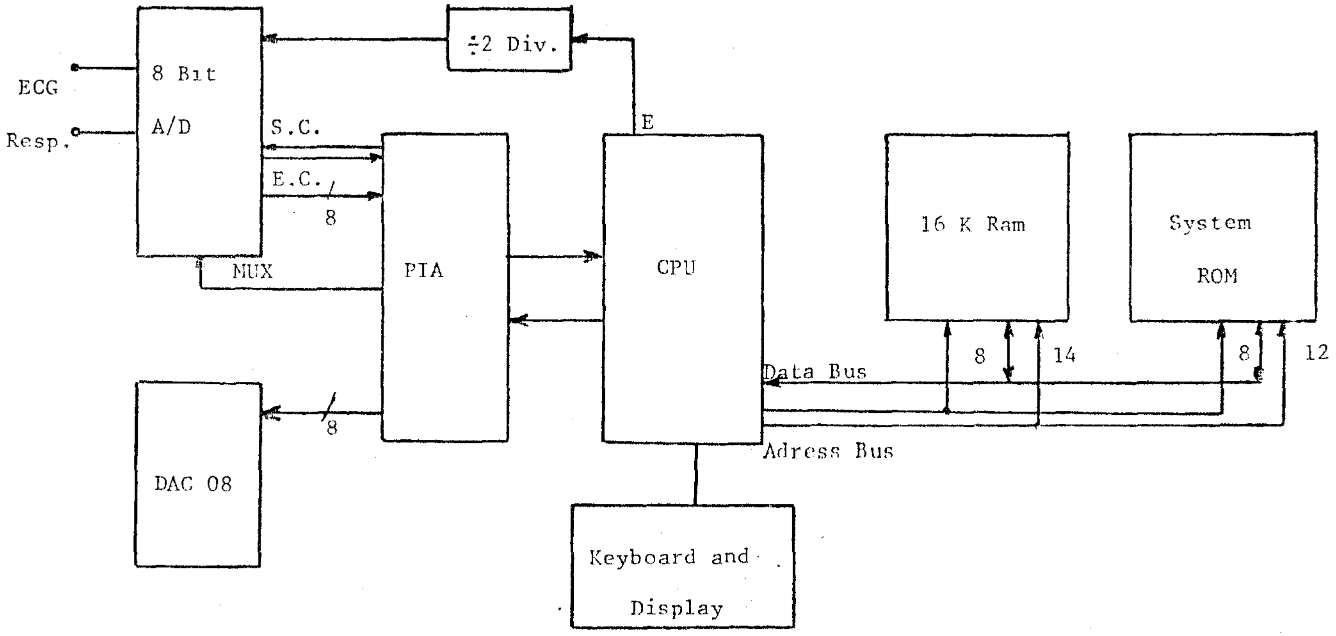


Fig.21 Block Diagram of the Microprocessor unit

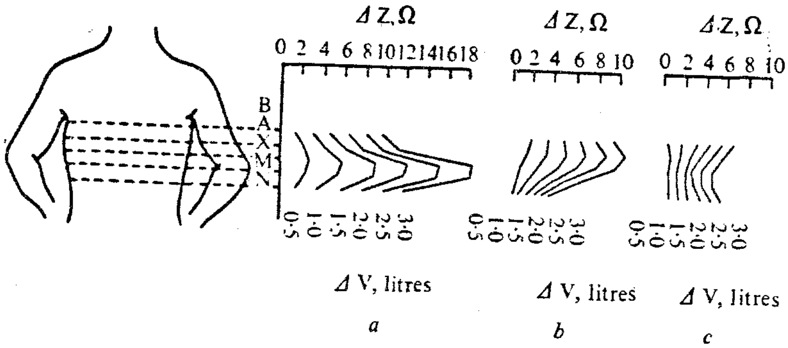
CHAPTER 4

SYSTEM EVALUATION AND DISCUSSIONS

4.1 Electrode Placement:

Our experiments showed that the electrode placement positions are not very critical within +/-2cm range. However, the jelly coupling to the surface and the cleaning process do effect the quality of the ecg signal picked up with this system.

On the other hand, the electrode placement for obtaining the respiration signal is very critical, as one can observe the impedance change values from fig.22.



ΔZ against thoracic level for subjects representative of three somatotypes

A pair of electrodes (silver discs of diameter 3·5 cm) were moved along the midaxillary lines and ΔZ and ΔV were measured at the levels indicated

Spacing between the thoracic levels = 3·5 cm

a Subject: L.E.B., 5 ft 10 in 150 lb ectomorph
b Subject: O.G., 5 ft 10 in 175 lb mesomorph
c Subject: J.D.M., 6 ft 2 in 220 lb endomorph

Fig. 22. The impedance change ranges vs electrode placement.

Another problem occured during experiments, is the base impedance varies from one person to another depending upon the humidity of the skin and the fatty tissues of the patient.Therefore, for some people a variable resistor must be placed on one branch of the respiration bridge and should be adjusted before use.

4.2 ECG section ;

The amplifier and the voltage controlled oscillator of this section works properly with the given figures in chapter 3.Here, the timing and voltage waveforms of the subcarrier modulation signal is presented for illustration.

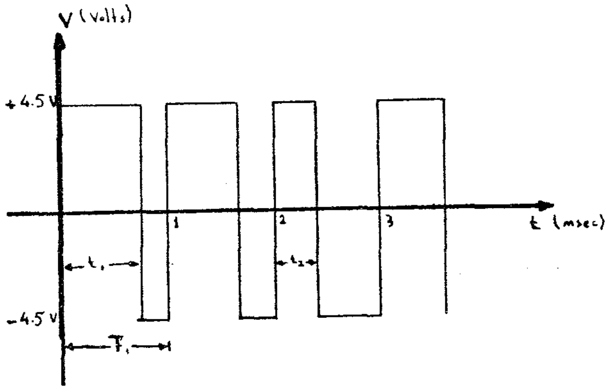


Fig.23 Subcarrier modulator waveform

4.3 Respiration section :

If one takes care of the points mentioned in section 4.1,the transmitter amplifier and the receiver demodulator presents no problems. However the offset potentiometer must be adjusted properly for not causing the overlapping of the fm and pwm periods.

4.4 RF transmitter :

The rf transmitter board is realised in a really small area,and in the beginning the unwanted couplings caused problems.With the configuration shown in the circuit diagram, I was able to operate it in the frequency range of 88 MHz to 160 MHz by achieving different tuning points with the doubler and tripler stages. The output waveform could be controlled from 2V peak to peak, to 5 V peak to peak, however, the power consumption of the stage was varying from 10 mA to 30 mA also.

4.5 The receiver front end:

The configuration of the FM tuner is quite a standard one, however since the transmitter-receiver alignment sets were not available, I couldn't manage to tune the receiver to transmitter properly.Therefore in the beginning, I used a standard TV tuner to pick up the transmitted signal.A narrowband commercial receiver board would follow this tuner and recover the transmitted signal.However, after I worked on this system for more than a month, I saw that, practically it is impossible to realise this system. Therefore, I changed the design to a standard FM tuner section and set up the demonstration part with it.

4.6 Frequency synthesizer:

The circuit shown in fig.18 is breadboarded and shown that operating well.

4.7 Signal demodulation and microprocessor board:

The demodulator section also is working properly.However since there are many microprocessors available on the market, I planned to use a personel computer , having all the specifications that the board we presented on chapter 2.,I used a CBM 64 for generating most of the signals.

4.8 Packaging and power supply :

The packaging specifications;

weight:235 gr. nominal

HT:2.5 cm, Lth:14 cm, Wdth:8.5 cm.

With these specifications, one can easily see that the transmitter packaging is completely ergonomic and suitable for our purposes.The weight can be decreased more, since it was the prototype, we used sockets for every IC.

The accesories are kept minimum, by using the leads for the pick up of both the respiration and ecg signals and as the antenna for the transmitter.The electrode jack is also used for power monitor and battery switch.

If we check the power consumption of the stages;

Power monitoring	:	2mA
Transmitter	:	15mA
ECG & Resp.Ampl	:	3.5mA
Modulators	:	2mA

These values add up to 22,5mA. (Since they were rather expensive, I didn't use the low power op amps in the transmitter, that are pin competible to the ones I used.The calculations, however are done according to the low power versions.)

So with a 75 mAHr rechargable battery, the unit can safely monitor a patient for three hours.

4.9 Range :

Our demonstration system, although it has many diffefences compared to the designed system, worked well, in the same building the range was approximately 50 m on the same flat.

CHAPTER 5

FUTUREWORK AND CONCLUSION

The history of the Biotelemetry is not very old in the area of bioinstrumentation and covered a long way since it first started.

If we look at the changes in Turkey in the last few years, the release of CB equipment and the new import regime, one can expect that a useful area of bioinstrumentation, namely the biotelemetry may be adequetly come into use in many hospitals, perhaps according to the CCITT standards. Furthermore a line telemetry system in Istanbul city, has just getting started .

Taking these points into consideration the designed system is kept flexible enough to allow connections to a line telemetry system or an ambulatory arrythmia monitoring system easily.

As the designed system is rewieved, one can judge that this system is a comperatively simple and low cost system, requiring no special or extra components other than the ones available on the market, and most of the expensive research is done.

The disadvantages of the system is common to all other Biotelemetry systems such as the requirement of an allowed standard channel, composition of many different blocks of electronics, etc.

However I think throughout the thesis I was able to emphesize

-the measurement of respiration signal, with the impedance change method,

-the scanning of the patients authomatically under the control of the microprocessor card,

-to check and analyze patient data with the use of the software written on the microprocessor system,

-finally the cost efficiency of the system due to the use of simple and standard design of the circuitry and the advantage of the ability of using one CRT display for the display of both the respiration and ECG signals of five patients.

APPENDIX A:

Some useful design equations and analysis of the special blocks, used in the design of the system.

ECG Amplifier:

The gain of the first stage, as explained in chapter three, cannot exceed 15.

So if we choose R1=10K, then RF1=150K.

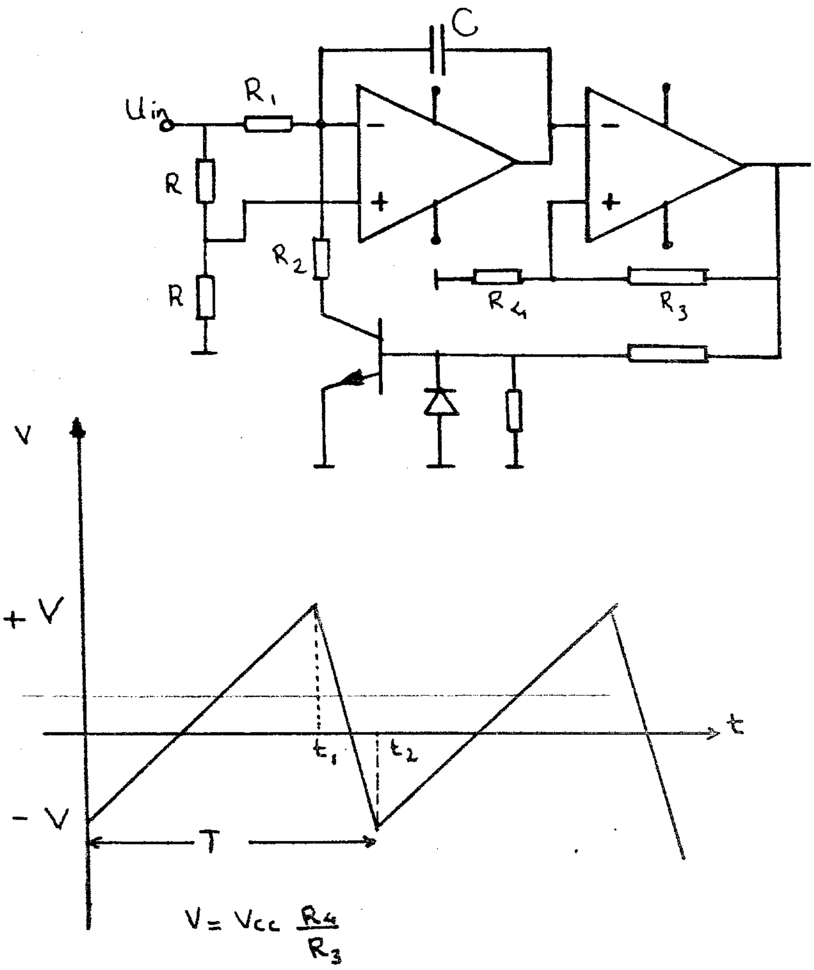
Inorder to get rid of the D.C. offset and drift problems, when we a.c. couple the second stage to the first stage, the lower cut off frequency is set by C1 and R2. For obtaining a lower cut off frequency, R2 must be large since C1 cannot be larger than 1 uF practically as a nonpolar capacitor.

However the gain of the second stage decreases if R2 increases.For the selected lower cut off frequency as 0.6 Hz. the values are R2=390K and C1=680nF.

$$F=\frac{1}{2*\pi*R2*C1} \qquad F=\frac{1}{2*\pi*R3*C3}$$

The higher cutoff frequency is set by the feedback capacitor resistor branch of the second and third stages as approximately to 90 Hz.

Voltage controlled oscillator:



During charge cycle;

$(t) = -V_{cc} \cdot \frac{R_4}{R_3} + \frac{U_{in}}{2R_1C}\, t$

$t_1 = V_{cc} \cdot \frac{R_4}{R_3} \cdot \frac{2R_1C}{U_{in}}$

From the discharge cycle;

$t_2 = V_{cc} \frac{R_4}{R_3} \cdot \frac{2R_2C}{U_{in}}$

$f = \frac{1}{T}$ where $T = t_1 + t_2$

$T = t_1 + t_2 = \frac{2V_{cc}.R_4.C}{R_3.U_{in}}.(R_1+R_2)$

Therefore: $f = \frac{R_3}{2.V_{cc}.R_4.C.(R_1+R_2)} \times U_{in}$

Oscillator stages, design and analysis:

For the general circuit configuration as shon in the figure below, the center frequency is set by the formula w=1/ LC
The equivalent capacitor must be at least 10 times greater than the transistor's and other parasitic capacitors, that effect the frequency.

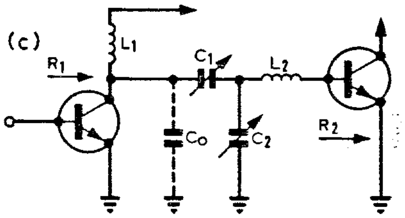
C =C +C1//C2

Also C1/C2 approximately sets the transformation ratio of the feedback network, n.

For stability conditions, the signal sent back must be in the order of several hundred mVs.
For this level of input, the transistor's large signal parameters are valid. The large signal gain is related to the small signal transconductance as shown in figure below. Once the small signal transconductance is determined, the stage gain and therefore the loss ratio n is known. Therefore C1, C2, and L is found from the frequency information and the set bias current IEQ must satisfy the small signal gain. An excellent discussion can be found in ref.7

RF transmitter stages;

The design of the rf transmitter section is rather standard and the only requirement is the special care taken in the design of the pcb and the component layout. For all of the frequency doubling stages and to the output stage the coupling network shown below is used.



, Interstage coupling networks.

For $R_1 > R_2$

$$(1)\quad X_{L_1} = \frac{R_1}{Q_L}$$

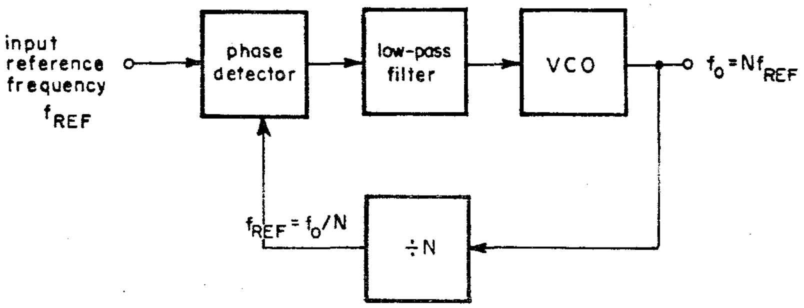
$$(2)\quad X_{L_2} = \frac{R_2}{Q_L} \cdot \frac{\left[\sqrt{\frac{R_1}{R_2}} - 1\right]}{\left[1 - \frac{R_1}{Q_L X_{C_0}}\right]}$$

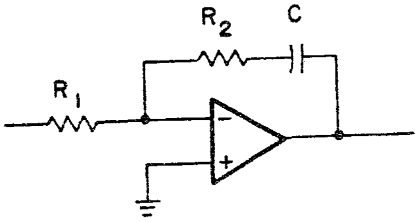
$$(3)\quad X_{C_1} = \frac{R_1}{Q_L} \cdot \frac{\left[1 - \sqrt{\frac{R_2}{R_1}}\right]}{1 - \frac{R_1}{Q_L X_{C_0}}}$$

$$(4)\quad X_{C_2} = \frac{R_1}{Q_L} \cdot \frac{\sqrt{\frac{R_2}{R_1}}}{\left[1 - \frac{R_1}{Q_L X_{C_0}}\right]}$$

The frequency synthesizer;

The block diagram of the frequency synthesizer is shown below. Although a very good design guide is shown in bibliography, ref. 15, I wanted to give the main design formulas here. As it can be seen from the equations, one of the most important parameters of the PLL is the loop gain. The loop gain of the VCO is dependent upon the specific design of the stage.However if a standard CMOS circuit is going to be used in the system such as 4046 or 4044 4568 etc, the loop gain of the vco; KO=11*10E6 rad/sec/V , and for the phase comparator, KP=0.12 V/rad. can be used.





$$N_{max} = \frac{f_{o(max)}}{f_{REF}}$$

$$N_{min} = \frac{f_{o(min)}}{f_{REF}}$$

$$\zeta_{max} = \zeta_{min} \left(\frac{N_{max}}{N_{min}}\right)^{1/2}$$

$$\omega_{LPF} = \frac{1}{R_1C} \quad \text{(rad/s)}$$

$$C_{min} = \frac{K_\phi K_o}{N_{max}R_1\omega_n^2}$$

$K_\phi K_o$ (often referred to as the *dc loop gain*)

Table II
PARAMETERS OF PHYSIOLOGIC QUANTITIES

Parameter or measuring technique	Principal measurement range or parameter	Standard transducer or method	Signal frequency range (HZ)	Requirements for good recording (HZ)
Ballistocardiography (BCG)	0 7 mg	Accelerometer, strain gauge	DC 40	1 30
	0 - 100 μm	Displacement (LDVT)	DC 40	1 30
Bladder pressure	0 - 100 cm H_2O	Strain gauge manometer	DC 10	5 10
Blood flow	1 300 mℓ sec	Flowmeter (electromagnetic or ultrasonic)	1 20	1 20
Blood pressure (arterial)				
Direct	10—400 mm Hg	Strain gauge manometer	DC - 50	0.5 30
Indirect	25 400 mm Hg	Cuff, palpation	1 60	1 60
(Venous)	0—50 mm Hg	Strain gauge	DC 50	DC 30
Blood gases P_{O_2}	30 - 110 mm Hg	Specific electrode, volumetric or manometric	DC 2	DC 2
P_{CO_2}	40 - 100 mm Hg	Specific electrode, volumetric or manometric	DC 2	DC 2
P_{N_2}	1—3 mm Hg	Specific electrode, volumetric or manometric	DC 2	DC 2
P_{CO}	0.1—0.4 mm Hg	Specific electrode, volumetric or manometric	DC 2	DC 2
Blood pH	6.8—7.8 pH units	Specific electrode	DC - 2	DC - 2
Cardiac output	4—25 ℓ/min	Dye dilution, flowmeter	1 - 20	1 20
Electrocardiography (ECG)	0.5—4 mV	Skin electrodes	0.01 - 250	0.1 100
Electroencephalography (EEG)	5—300 μV	Scalp electrodes	DC – 150	0.2 50
(Electrocorticography and brain depth)	10—5000 μV	Brain surface or depth electrodes		
Electrogastrography	10—1000 μV	Skin surface electrodes	DC - 1	0.05 0.5
	0.5—80 mV	Stomach surface electrodes		
Electromyography (EMG)	0.1—5 mV	Needle electrodes	DC 10,000	20 8000
Eye potentials EOG	50—3500 μV	Contact electrodes	DC - 50	0.2 15
ERG	0—900 μV	Contact electrodes	DC – 50	DC - 20
Galvanic skin response (GSR)	1—500 KΩ	Skin electrodes	0.01—1	0.1 - 1
Gastric pH	3—13 pH units	pH electrode, antimony electrode	DC—1	DC—1
Gastrointestinal pressure	0—100 cm H_2O	Strain gauge manometer	DC—10	DC—10
Gastrointestinal forces	1—50 g	Displacement system, LVDT	DC—1	DC—1
Nerve potentials	0.01—3 mV	Surface or needle electrodes	DC—10,000	20—8000
Paleencephalography	0.2 50 Hz	Accelerometer on scalp	0.2—50	1—20
Phonocardiography (PCG)	Dynamic range 80 dB Threshold about 10^{-4} dynes cm^2	Microphone	5—2000	20—300
Plethysmography (volume change)	Varies with organ measured	Displacement chamber or impedance change	DC—30	DC—30
Circulatory	0 30 mℓ	Displacement chamber or impedance change	DC—30	DC—30
Respiratory functions:				
Pneumotachography (flow rate)	0 600 ℓ min	Pneumotachograph head and differential pressure	DC—40	0.1—5
Respiratory rate	2 - 50 min	Strain gauge on chest, impedance, nasal thermistor	0.1—10	0.1—5
Tidal volume	50 1000 mℓ breath	Above methods	0.1—10	0.1—5
Temperature of body	32 40°C 90 104°F	Thermistor, thermocouple	DC—0.1	DC—0.1

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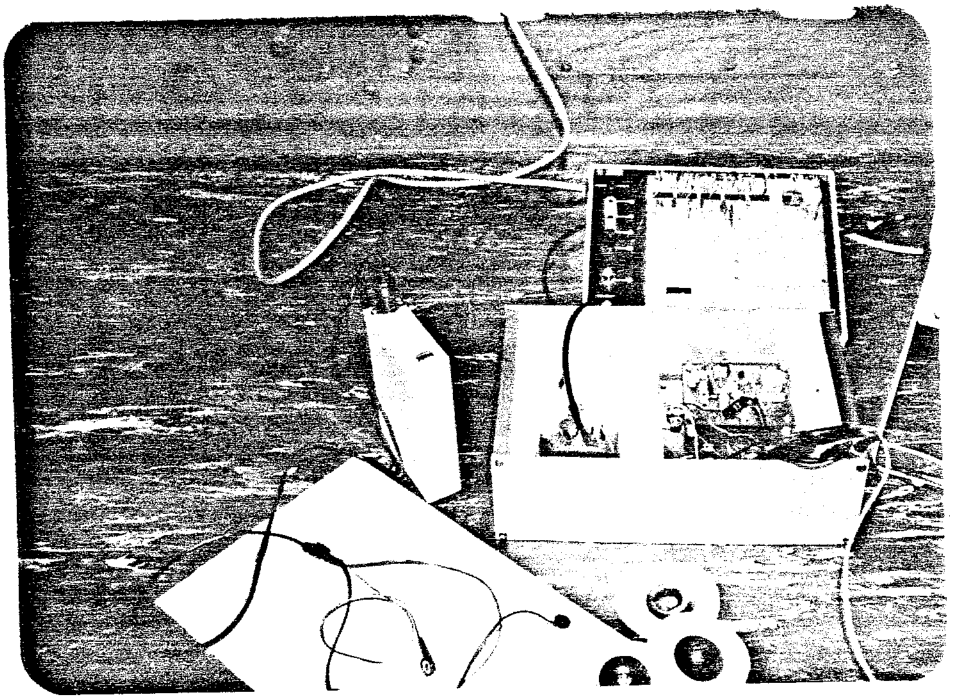
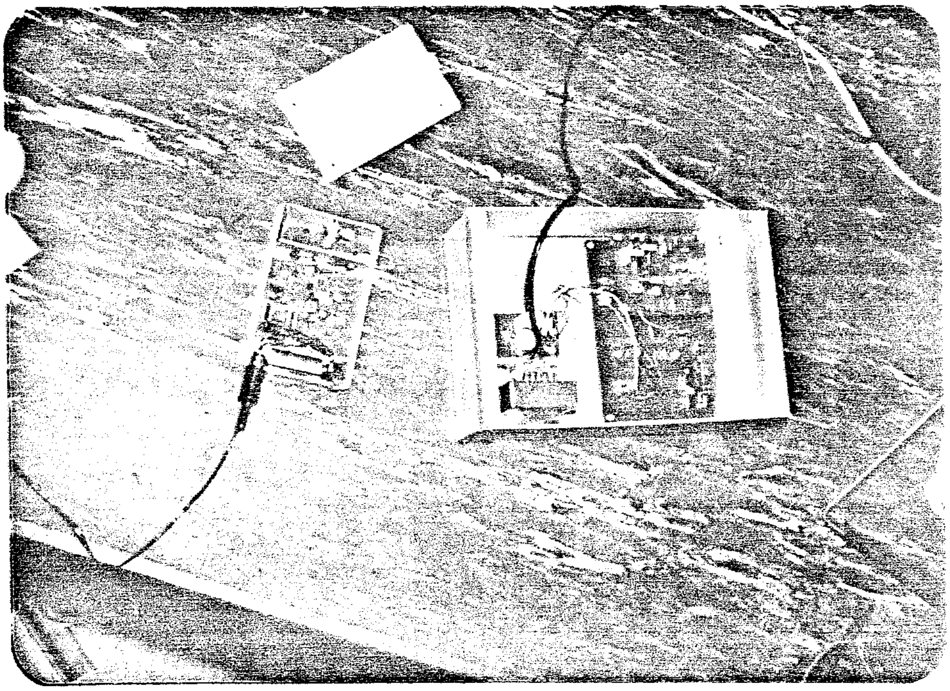


a) The transmitter unit is on the left, the receiver is in the middle, the frequency syathesizer is behind the receiver box.
In front of the transmitter, the cables and electrodes can be seen.

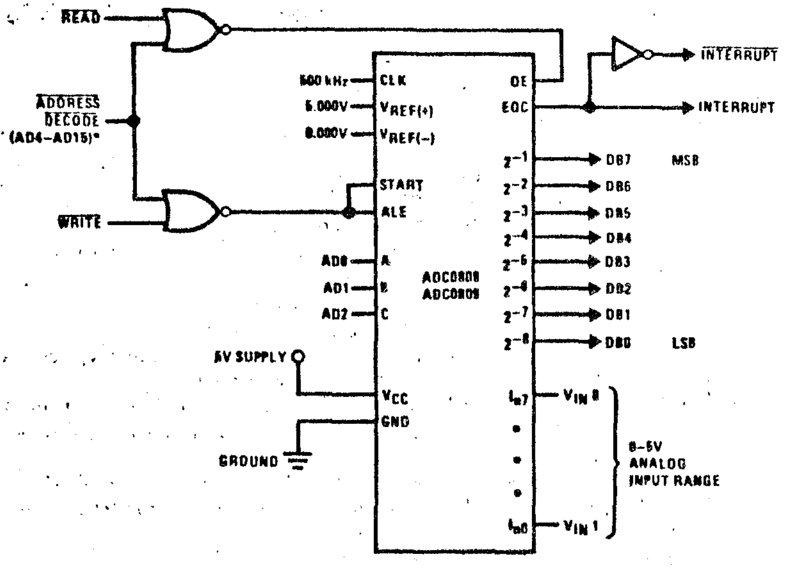


b) The internal structure and PCB assemblies of both the transmitter and the receiver is shown.

Fig.A. Photographs of the prototype of the designed system.

APPENDIX B:

The data sheets of the special components and ICs used in this thesis.



* Address latches needed for 8085 and SC/MP interfacing the ADC0808 to a microprocessor

MICROPROCESSOR INTERFACE TABLE

PROCESSOR	$\overline{\text{READ}}$	$\overline{\text{WRITE}}$	INTERRUPT (COMMENT)
8080	$\overline{\text{MEMR}}$	$\overline{\text{MEMW}}$	INTR (Thru RST Circuit)
8085	$\overline{\text{RD}}$	$\overline{\text{WR}}$	INTR (Thru RST Circuit)
Z-80	$\overline{\text{RD}}$	$\overline{\text{WR}}$	$\overline{\text{INT}}$ (Thru RST Circuit, Mode 0)
SC/MP	NRDS	NWDS	SA (Thru Sense A)
6800	VMA·ϕ2·R/W	VMA·ϕ2·$\overline{\text{R/W}}$	$\overline{\text{IRQA}}$ or $\overline{\text{IRQB}}$ (Thru PIA)

ng Information

TEMPERATURE RANGE		−40°C to +85°C		−55°C to +125°C
Error	± 1/2 Bit Unadjusted	ADC0808CCN	ADC0808CCJ	ADC0808CJ
	± 1 Bit Unadjusted	ADC0809CCN		
Package Outline		N28A Molded DIP	J28A Hermetic DIP	J28A Hermetic DIP

Semiconductor

ADC0808, ADC0809 8-Bit μP Compatible A/D Converters With 8-Channel Multiplexer

General Description

The ADC0808, ADC0809 data acquisition component is a monolithic CMOS device with an 8-bit analog-to-digital converter, 8-channel multiplexer and microprocessor compatible control logic. The 8-bit A/D converter uses successive approximation as the conversion technique. The converter features a high impedance chopper stabilized comparator, a 256R voltage divider with analog switch tree and a successive approximation register. The 8-channel multiplexer can directly access any of 8-single-ended analog signals.

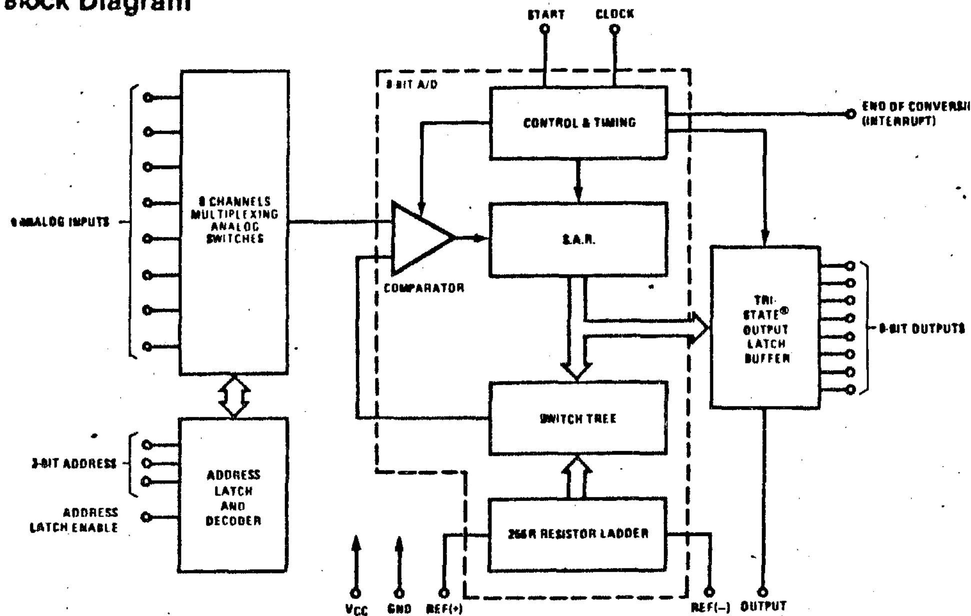
The device eliminates the need for external zero and full-scale adjustments. Easy interfacing to microprocessors is provided by the latched and decoded multiplexer address inputs and latched TTL TRI-STATE® outputs.

The design of the ADC0808, ADC0809 has been optimized by incorporating the most desirable aspects of several A/D conversion techniques. The ADC0808, ADC0809 offers high speed, high accuracy, minimal temperature dependence, excellent long-term accuracy and repeatability and consumes minimal power. These features make this device ideally suited to applications from process and machine control to consumer and automotive applications. For 16-channel multiplexer with common output (sample/hold port) see ADC0816 data sheet.

Features

- Resolution — 8-bits
- Total unadjusted error — ± 1/2 LSB and ± 1 LSB
- No missing codes
- Conversion time — 100 μs
- Single supply — 5 V_{DC}
- Operates ratiometrically or with 5 V_{DC} or analog s adjusted voltage reference
- 8-channel multiplexer with latched control logic
- Easy interface to all microprocessors, or opera "stand alone"
- Outputs meet T^2L voltage level specifications
- 0V to 5V analog input voltage range with single supply
- No zero or full-scale adjust required
- Standard hermetic or molded 28-pin DIP package
- Temperature range −40°C to +85°C or −55°C +125°C
- Low power consumption — 15 mW
- Latched TRI-STATE® output

Block Diagram



(Notes 1 and 2)

Supply Voltage (V_{CC}) (Note 3)	6.5V
Voltage at Any Pin Except Control Inputs	−0.3V to (V_{CC} + 0.3V)
Voltage at Control Inputs (START, OE, CLOCK, ALE, ADD A, ADD B, ADD C)	−0.3V to +15V
Storage Temperature Range	−65°C to +150°C
Package Dissipation at $T_A = 25°C$	875 mW
Lead Temperature (Soldering, 10 seconds)	300°C

Temperature Range (Note 1)	$T_{MIN} \le T_A \le$
ADC0808CJ	$-55°C \le T_A \le$
ADC0808CCJ, ADC0808CCN, ADC0809CCN	$-40°C \le T_A \le$
Range of V_{CC} (Note 1)	4.5 V_{DC} to

Electrical Characteristics

Converter Specifications: $V_{CC} = 5\ V_{DC} = V_{REF(+)}$, $V_{REF(-)} = GND$, $T_{MIN} \le T_A \le T_{MAX}$ and $f_{CLK} = 640$ kHz unless otherwise stated.

	Parameter	Conditions	Min	Typ	Max	U
	ADC0808					
	Total Unadjusted Error	25°C			±1/2	
	(Note 5)	T_{MIN} to T_{MAX}			±3/4	
	ADC0809					
	Total Unadjusted Error	0°C to 70°C			±1	
	(Note 5)	T_{MIN} to T_{MAX}			±1 1/4	
	Input Resistance	From Ref(+) to Ref(−)	1.0	2.5		
	Analog Input Voltage Range	(Note 4) V(+) or V(−)	GND−0.10		V_{CC}+0.10	
$V_{REF(+)}$	Voltage, Top of Ladder	Measured at Ref(+)		V_{CC}	V_{CC}+0.1	
$\frac{V_{REF(+)}+V_{REF(-)}}{2}$	Voltage, Center of Ladder		V_{CC}/2−0.1	V_{CC}/2	V_{CC}/2+0.1	
$V_{REF(-)}$	Voltage, Bottom of Ladder	Measured at Ref(−)	−0.1	0		
	Comparator Input Current	f_c = 640 kHz, (Note 6)	−2	±0.5	2	

Electrical Characteristics

Digital Levels and DC Specifications: ADC0808CJ $4.5V \le V_{CC} \le 5.5V$, $-55°C \le T_A \le +125°C$ unless otherwise noted ADC0808CCJ, ADC0808CCN, and ADC0809CCN $4.75 \le V_{CC} \le 5.25V$, $-40°C \le T_A \le +85°C$ unless otherwise noted

	Parameter	Conditions	Min	Typ	Max	U
ANALOG MULTIPLEXER						
$I_{OFF(+)}$	OFF Channel Leakage Current	V_{CC} = 5V, V_{IN} = 5V, T_A = 25°C		10	200	
		T_{MIN} to T_{MAX}			1.0	
$I_{OFF(-)}$	OFF Channel Leakage Current	V_{CC} = 5V, V_{IN} = 0, T_A = 25°C	−200	−10		
		T_{MIN} to T_{MAX}	−1.0			
CONTROL INPUTS						
$V_{IN(1)}$	Logical "1" Input Voltage		V_{CC}−1.5			
$V_{IN(0)}$	Logical "0" Input Voltage				1.5	
$I_{IN(1)}$	Logical "1" Input Current (The Control Inputs)	V_{IN} = 15V			1.0	

trical Characteristics (Continued)

Levels and DC Specifications: ADC0808CJ $4.5V \le V_{CC} \le 5.5V$, $-55°C \le T_A \le +125°C$ unless otherwise n 08CCJ, ADC0808CCN, and ADC0809CCN $4.75 \le V_{CC} \le 5.25V$, $-40°C \le T_A \le +85°C$ unless otherwise not

	Parameter	Conditions	Min	Typ	Ma
A OUTPUTS AND EOC (INTERRUPT)					
	Logical "1" Output Voltage	$I_O = -360\ \mu A$	V_{CC}−0.4		
	Logical "0" Output Voltage	I_O = 1.6 mA			0.4
	Logical "0" Output Voltage EOC	I_O = 1.2 mA			0.4
	TRI-STATE Output Current	V_O = 5V			3
		V_O = 0	−3		

ctrical Characteristics

Specifications: $V_{CC} = V_{REF(+)} = 5V$, $V_{REF(-)} = GND$, $t_r = t_f = 20$ ns and $T_A = 25°C$ unless otherwise noted.

Symbol	Parameter	Conditions	Min	Typ	Max
	Minimum Start Pulse Width	*(Figure 5)*		100	200
	Minimum ALE Pulse Width	*(Figure 5)*		100	200
	Minimum Address Set-Up Time	*(Figure 5)*		25	50
	Minimum Address Hold Time	*(Figure 5)*		25	50
	Analog MUX Delay Time From ALE	$R_S = 0\Omega$ *(Figure 5)*		1	2.5
	OE Control to Q Logic State	C_L = 50 pF, R_L = 10k *(Figure 8)*		125	250
	OE Control to Hi-Z	C_L = 10 pF, R_L = 10k *(Figure 8)*		125	250
	Conversion Time	f_c = 640 kHz, *(Figure 5)* (Note 7)	90	100	116
	Clock Frequency		10	640	1280
	EOC Delay Time	*(Figure 5)*	0		8+2
	Input Capacitance	At Control Inputs		10	15
	TRI-STATE® Output Capacitance	At TRI-STATE® Outputs, (Note 12)		10	15

Absolute maximum ratings are those values beyond which the life of the device may be impaired.

All voltages are measured with respect to GND, unless otherwise specified.

A zener diode exists, internally, from V_{CC} to GND and has a typical breakdown voltage of 7 V_{DC}.

Two on-chip diodes are tied to each analog input which will forward conduct for analog input voltages one diode drop below ground or on than the V_{CC} supply. The spec allows 100 mV forward bias of either diode. This means that as long as the analog V_{IN} does not excee by more than 100 mV, the output code will be correct. To achieve an absolute 0 V_{DC} to 5 V_{DC} input voltage range will therefore require a m age of 4.900 V_{DC} over temperature variations, initial tolerance and loading.

Total unadjusted error includes offset, full-scale, linearity, and multiplexer errors. See *Figure 3*. None of these A/Ds requires a zero or full- , if an all zero code is desired for an analog input other than 0.0V, or if a narrow full-scale span exists (for example: 0.5V to 4.5V full-scale) can be adjusted to achieve this. See *Figure 13*.

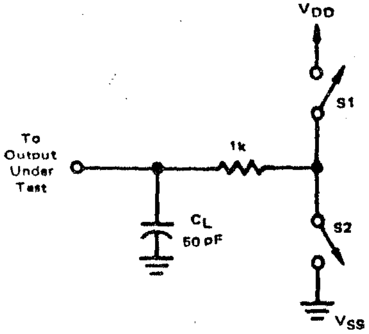
Comparator input current is a bias current into or out of the chopper stabilized comparator. The bias current varies directly with clock fr temperature dependence *(Figure 6)*. See paragraph 4.0.

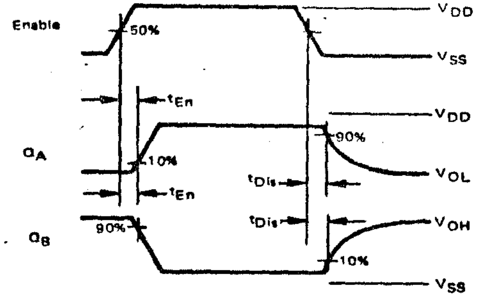
The outputs of the data register are updated one clock cycle before the rising edge of EOC.

THREE-STATE ENABLE/DISABLE DELAYS

Set, Reset, and Switch Conditions for 3-State Tests.

TEST	S	R	MC14043B			MC14044B		
			S1	S2	Q	S1	S2	Q
t_{En}	V_{DD}	V_{SS}	Open	Closed	A	Closed	Open	B
t_{En}	V_{SS}	V_{DD}	Closed	Open	B	Open	Closed	A
t_{Dis}	V_{DD}	V_{SS}	Open	Closed	A	Closed	Open	B
t_{Dis}	V_{SS}	V_{DD}	Closed	Open	B	Open	Closed	A





Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

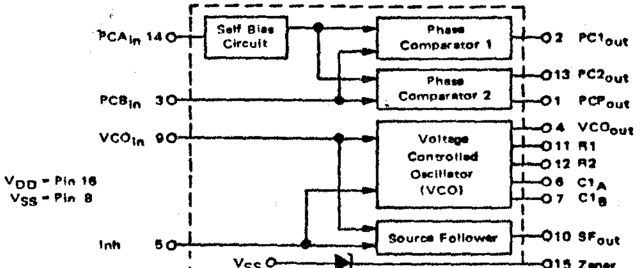
PHASE-LOCKED LOOP

The MC14046B phase-locked loop contains two phase comparators, a voltage-controlled oscillator (VCO), source follower, and zener diode. The comparators have two common signal inputs. PCA_{in} and PCB_{in}. Input PCA_{in} can be used directly coupled to large voltage signals, or indirectly coupled (with a series capacitor) to small voltage signals. The self-bias circuit adjusts small voltage signals in the linear region of the amplifier. Phase comparator 1 (an exclusive OR gate) provides a digital error signal $PC1_{out}$, and maintains 90° phase shift at the center frequency between PCA_{in} and PCB_{in} signals (both at 50% duty cycle). Phase comparator 2 (with leading edge sensing logic) provides digital error signals $PC2_{out}$ and PCP_{out}, and maintains a 0° phase shift between PCA_{in} and PCB_{in} signals (duty cycle is immaterial). The linear VCO produces an output signal VCO_{out} whose frequency is determined by the voltage of input VCO_{in} and the capacitor and resistors connected to pins $C1_A$, $C1_B$, R1, and R2. The source-follower output SF_{out} with an external resistor is used where the VCO_{in} signal is needed but no loading can be tolerated. The inhibit input Inh, when high, disables the VCO and source follower to minimize standby power consumption. The zener diode can be used to assist in power supply regulation.

Applications include FM and FSK modulation and demodulation, frequency synthesis and multiplication, frequency discrimination, tone decoding, data synchronization and conditioning, voltage-to-frequency conversion and motor speed control.

- VCO Frequency = 1.4 MHz Typical @ V_{DD} = 10 Vdc
- VCO Frequency Drift with Temperature = 0.04%/°C Typical @ V_{DD} = 10 Vdc
- VCO Linearity = 1% Typical
- Quiescent Current = 5.0 nA/package typical @ 5 Vdc
- Low Dynamic Power Dissipation – 70 μW Typical @ f_0 = 10 kHz, V_{DD} = 5.0 Vdc, R1 = 1.0 MΩ, R2 = ∞, R_{SF} = ∞
- Buffered Outputs Compatible with MHTL and Low-Power TTL
- Diode Protection on All Inputs
- Supply Voltage Range = 3.0 to 18 Vdc
- Pin-for-Pin Replacement for CD4046

BLOCK DIAGRAM



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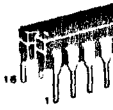

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MC14XXXB .

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[illegible]	V_{DD}	[illegible]	Vdc
Input Voltage All Inputs	V_{in}	-0.5 to V_{DD} + 0.5	Vdc
DC Current Drain per Pin	I	10	mAdc
Operating Temperature Range – AL Device CL/CP Device	T_A	-55 to +125 -40 to +85	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C

ECTRICAL CHARACTERISTICS

Characteristic	Symbol	V_{DD} Vdc	T_{low}* Min	T_{low}* Max	25°C Min	25°C Typ	25°C Max	T_{high}* Min	T_{high}* Max	Unit
tput Voltage "0" Level V_{in} = V_{DD} or 0	V_{OL}	5.0	–	0.05	–	0	0.05	–	0.05	Vdc
		10	–	0.05	–	0	0.05	–	0.05	
		15	–	0.05	–	0	0.05	–	0.05	
"1" Level V_{in} = 0 or V_{DD}	V_{OH}	5.0	4.95	–	4.95	5.0	–	4.95	–	Vdc
		10	9.95	–	9.95	10	–	9.95	–	
		15	14.95	–	14.95	15	–	14.95	–	
put Voltage# "0" Level	V_{IL}									Vdc
(V_O = 4.5 or 0.5 Vdc)		5.0	–	1.5	–	2.25	1.5	–	1.5	
(V_O = 9.0 or 1.0 Vdc)		10	–	3.0	–	4.50	3.0	–	3.0	
(V_O = 13.5 or 1.5 Vdc)		15	–	4.0	–	6.75	4.0	–	4.0	
"1" Level	V_{IH}									
(V_O = 0.5 or 4.5 Vdc)		5.0	3.5	–	3.5	2.75	–	3.5	–	Vdc
(V_O = 1.0 or 9.0 Vdc)		10	7.0	–	7.0	5.50	–	7.0	–	
(V_O = 1.5 or 13.5 Vdc)		15	11.0	–	11.0	8.25	–	11.0	–	
utput Drive Current (AL Device)	I_{OH}									mAdc
(V_{OH} = 2.5 Vdc) Source		5.0	–1.2	–	–1.0	–1.7	–	–0.7	–	
(V_{OH} = 4.6 Vdc)		5.0	–0.25	–	–0.2	–0.36	–	–0.14	–	
(V_{OH} = 9.5 Vdc)		10	–0.62	–	–0.5	–0.9	–	–0.35	–	
(V_{OH} = 13.5 Vdc)		15	–1.8	–	–1.5	–3.5	–	–1.1	–	
(V_{OL} = 0.4 Vdc) Sink	I_{OL}	5.0	0.64	–	0.51	0.88	–	0.36	–	mAdc
(V_{OL} = 0.5 Vdc)		10	1.6	–	1.3	2.25	–	0.9	–	
(V_{OL} = 1.5 Vdc)		15	4.2	–	3.4	8.8	–	2.4	–	
utput Drive Current (CL/CP Device)	I_{OH}									mAdc
(V_{OH} = 2.5 Vdc) Source		5.0	–1.0	–	–0.8	–1.7	–	–0.6	–	
(V_{OH} = 4.6 Vdc)		5.0	–0.2	–	–0.16	–0.36	–	–0.12	–	
(V_{OH} = 9.5 Vdc)		10	–0.5	–	–0.4	–0.9	–	–0.3	–	
(V_{OH} = 13.5 Vdc)		15	–1.4	–	–1.2	–3.5	–	–1.0	–	
(V_{OL} = 0.4 Vdc) Sink	I_{OL}	5.0	0.52	–	0.44	0.88	–	0.36	–	mAdc
(V_{OL} = 0.5 Vdc)		10	1.3	–	1.1	2.25	–	0.9	–	
(V_{OL} = 1.5 Vdc)		15	3.6	–	3.0	8.8	–	2.4	–	
put Current (AL Device)	I_{in}	15	–	±0.1	–	±0.00001	±0.1	–	±1.0	µAdc
put Current (CL/CP Device)	I_{in}	15	–	±0.3	–	±0.00001	±0.3	–	±1.0	µAdc
put Capacitance (V_{in} = 0)	C_{in}	–	–	–	–	5.0	7.5	–	–	pF
uiescent Current (AL Device) (Per Package) (Inh = "1" and PCA = "1")	I_{DD}	5.0	–	5.0	–	0.005	5.0	–	150	µAdc
		10	–	10	–	0.010	10	–	300	
		15	–	20	–	0.015	20	–	600	
uiescent Current (CL/CP Device) (Per Package) (Inh = "1" and PCA = "1")	I_{DD}	5.0	–	20	–	0.005	20	–	150	µAdc
		10	–	40	–	0.010	40	–	300	
		15	–	80	–	0.015	80	–	600	
otal Supply Current † (Inh = "0", f_o = 10 kHz, C_L = 50 pF, R1 = 1 MΩ, R2 = ∞, R_{SF} = ∞, and 50% Duty Cycle)	I_T	5.0	I_T = (1.46 µA/kHz) f + I_{DD}							µAdc
		10	I_T = (2.91 µA/kHz) f + I_{DD}							
		15	I_T = (4.37 µA/kHz) f + I_{DD}							

$_{ow}$ = -55°C for AL Device, -40°C for CL/CP Device.

$_{igh}$ = +125°C for AL Device, +85°C for CL/CP Device.

oise immunity specified for worst-case input combination.

oise Margin for both "1" and "0" level = 1.0 Vdc min @ V_{DD} = 5.0 Vdc
2.0 Vdc min @ V_{DD} = 10 Vdc
2.5 Vdc min @ V_{DD} = 15 Vdc

o Calculate Total Current in General:

$$I_T \approx 2.2 \times V_{DD} \left(\frac{VCO_{in} - 1.65}{R1} + \frac{V_{DD} - 1.35}{R2}\right)^{3/4} + 1.6 \times \left(\frac{VCO_{in} - 1.65}{R_{SF}}\right)^{3/4} + 1 \times 10^{-3}(C_L + 9) V_{DD}\ f +$$

$$1 \times 10^{-1} V_{DD}^2 \left(\frac{100 - \%\text{ Duty Cycle of } PCA_{in}}{100}\right) + I_Q$$

where: I_T in µA, C_L in pF, VCO_{in}, V_{DD} in Vdc, f in KHz, and R1, R2, R_{SF} in MΩ, C_L on VCO_{out}.

ELECTRICAL CHARACTERISTICS* (C_L = 50 pF, T_A = 25°C)

Characteristic	Symbol	V_{DD} Vdc	Minimum AL Device	Minimum CL/CP Device	Typical All Types	Ma AL Device
Output Rise Time	t_r					
t_r = (3.0 ns/pF) C_L + 30 ns		5.0	–	–	180	350
t_r = (1.5 ns/pF) C_L + 15 ns		10	–	–	90	150
t_r = (1.1 ns/pF) C_L + 10 ns		15	–	–	65	110
Output Fall Time	t_f					
t_f = (1.5 ns/pF) C_L + 25 ns		5.0	–	–	100	175
t_f = (0.75 ns/pF) C_L + 12.5 ns		10	–	–	50	75
t_f = (0.55 ns/pF) C_L + 9.5 ns		15	–	–	37	55

PHASE COMPARATORS 1 and 2

Characteristic	Symbol	V_{DD} Vdc	Minimum AL Device	Minimum CL/CP Device	Typical All Types	Ma AL Device
Input Resistance – PCA_{in}	R_{in}	5.0	1.0	1.0	2.0	–
		10	0.2	0.2	0.4	–
		15	0.1	0.1	0.2	–
– PCB_{in}	R_{in}	15	150	15	1500	–
Minimum Input Sensitivity AC Coupled – PCA_{in} C series = 1000 pF, f = 50 kHz	V_{in}	5.0	–	–	200	300
		10	–	–	400	600
		15	–	–	700	1050
DC Coupled – PCA_{in}, PCB_{in}	–	5 to 15	See Noise Immunity			

VOLTAGE CONTROLLED OSCILLATOR (VCO)

Characteristic	Symbol	V_{DD} Vdc	Minimum AL Device	Minimum CL/CP Device	Typical All Types	Ma AL Device
Maximum Frequency (VCO_{in} = V_{DD}, C1 = 50 pF, R1 = 5 kΩ, and R2 = ∞)	f_{max}	5.0	0.50	0.35	0.70	–
		10	1.0	0.7	1.4	–
		15	1.4	1.0	1.9	–
Temperature – Frequency Stability (R2 = ∞)	–	5.0	–	–	0.12	–
		10	–	–	0.04	–
		15	–	–	0.015	–
Linearity (R2 = ∞)	–					
(VCO_{in} = 2.50 V ± 0.30 V, R1 ≥ 10 kΩ)		5.0	–	–	1	–
(VCO_{in} = 5.00 V ± 2.50 V, R1 ≥ 400 kΩ)		10	–	–	1	–
(VCO_{in} = 7.50 V ± 5.00 V, R1 ≥ 1000 kΩ)		15	–	–	1	–
Output Duty Cycle	–	5 to 15	–	–	50	–
Input Resistance – VCO_{in}	R_{in}	15	150	15	1500	–

SOURCE-FOLLOWER

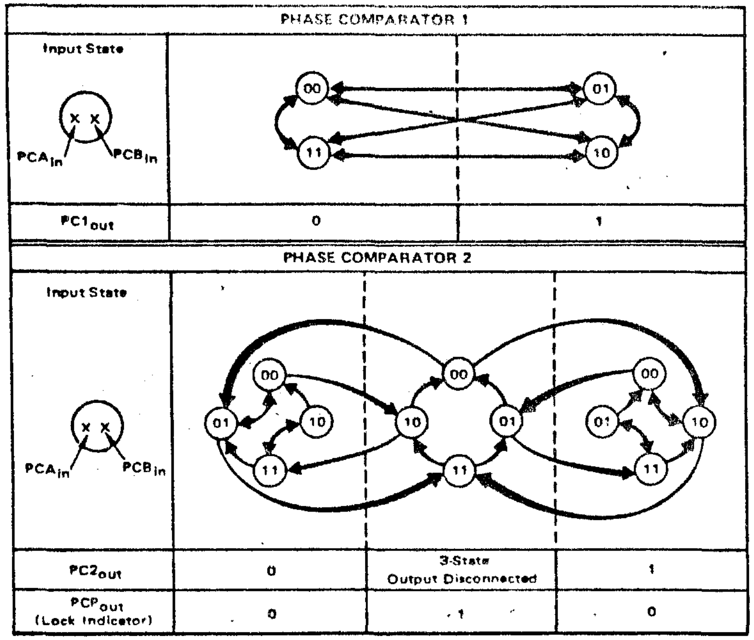
Characteristic	Symbol	V_{DD} Vdc	Minimum AL Device	Minimum CL/CP Device	Typical All Types	Ma AL Device
Offset Voltage (VCO_{in} minus SF_{out}, R_{SF} > 50 kΩ)	–	5.0	–	–	1.65	2.2
		10	–	–	1.65	2.2
		15	–	–	1.65	2.2
Linearity	–					
(VCO_{in} = 2.50 V ± 0.30 V, R_{SF} > 50 kΩ)		5.0	–	–	0.1	–
(VCO_{in} = 5.00 V ± 2.50 V, R_{SF} > 50 kΩ)		10	–	–	0.6	–
(VCO_{in} = 7.50 V ± 5.00 V, R_{SF} > 50 kΩ)		15	–	–	0.8	–

ZENER DIODE

Characteristic	Symbol	V_{DD} Vdc	Minimum AL Device	Minimum CL/CP Device	Typical All Types	Ma AL Device
Zener Voltage (I_Z = 50 µA)	V_Z	–	6.7	6.3	7.0	7.3
Dynamic Resistance (I_Z = 1 mA)	R_Z	–	–	–	100	–

*The formula given is for the typical characteristics only.

FIGURE 1 – PHASE COMPARATORS STATE DIAGRAMS



Refer to Waveforms in Figure 3.

E 2 – DESIGN INFORMATION

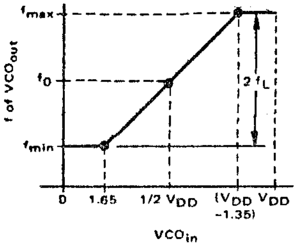
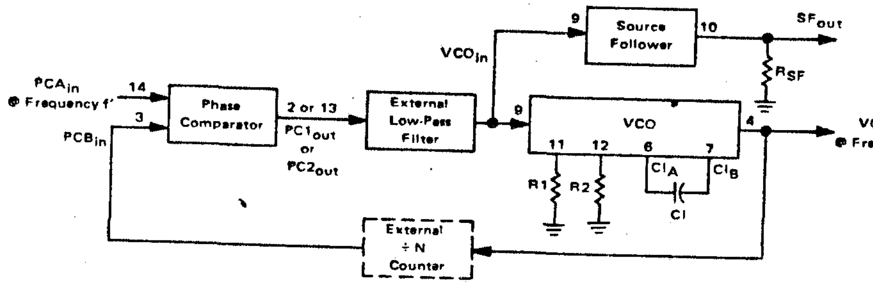
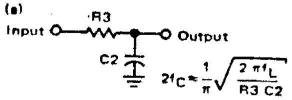
Characteristic	Using Phase Comparator 1	Using Phase Comparator 2
al on input PCA_{in}.	VCO in PLL system adjusts to center frequency (f_0).	VCO in PLL system adjusts to minimum frequency (f_{min}).
ngle between PCA_{in} and PCB_{in}.	90° at center frequency (f_0), approaching 0° and 180° at ends of lock range ($2f_L$).	Always 0° in lock (positive rising edges).
on harmonics of center frequency.	Yes	No
nput noise rejection.	High	Low
equency range ($2f_L$).	The frequency range of the input signal on which the loop will stay locked if it was initially in lock. $2f_L$ = full VCO frequency range = $f_{max} - f_{min}$.	
e frequency range ($2f_C$).	The frequency range of the input signal on which the loop will lock if it was initially out of lock.	
	Depends on low-pass filter characteristics (see Figure 3). $f_C < f_L$	$f_C = f_L$
frequency (f_0).	The frequency of VCO_{out}, when VCO_{in} = 1/2 V_{DD}	
utput frequency (f). : This information is intended to be a design guide. Some ratory experimentation may be ired for fixed designs.	$f \approx \frac{K\left[\frac{VCO_{in}-1.65}{R1}+\frac{V_{DD}-1.35}{R2}\right]}{(C1+32)(V_{DD}+1.6)}$ MHz (at 25°C) where: V_{DD} in Vdc; 5.0 Vdc $\leq V_{DD} \leq$ 15 Vdc VCO_{in} in Vdc; 1.65 Vdc $\leq VCO_{in} \leq (V_{DD} - 1.35$ Vdc) R1 and R2 in MΩ; R1 $\geq$ 0.005 MΩ R2 $\leq$ 10 MΩ C1 in pF; C1 $\geq$ 50 pF K = 0.95 @ V_{DD} = 5.0 Vdc = 0.95 @ V_{DD} = 10 Vdc = 1.08 @ V_{DD} = 15 Vdc	

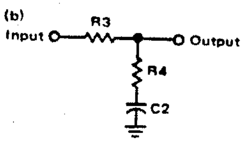
FIGURE 3 – GENERAL PHASE-LOCKED LOOP CONNECTIONS AND WAVEFORMS



Typical Low-Pass Filters



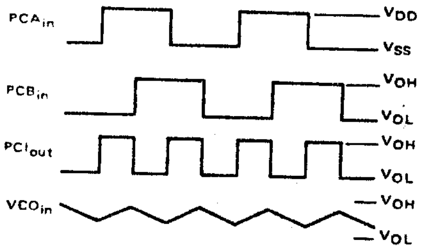
$$2f_C \approx \frac{1}{\pi}\sqrt{\frac{2\pi f_L}{R3\,C2}}$$



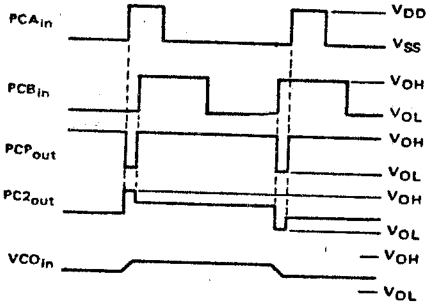
Note: for further information, see:
(1) F. Gardner, "Phase-Lock Techniques", John Wiley and Son, New York, 1966.
(2) G. S. Moschytz, "Miniature RC Filters Using Phase-Locked Loop", BSTJ, May, 1965.

Waveforms

Phase Comparator 1



Phase Comparator 2



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

Advance Information

PHASE COMPARATOR AND PROGRAMMABLE COUNTERS

The MC14568B consists of a phase comparator, a divide-by-4, 16, 64 or 100 counter and a programmable divide-by-N 4-bit binary counter (all positive-edge triggered) constructed with MOS P-channel and N-channel enhancement mode devices (complementary MOS) in a single monolithic structure.

This device can be used with:

- Both counters cascaded and the output of the second counter connected to the phase comparator (CTL high).
- Separate use of the programmable divide-by-N counter, for example cascaded with MC14569B (CTL low), MC14522B or MC14526B.

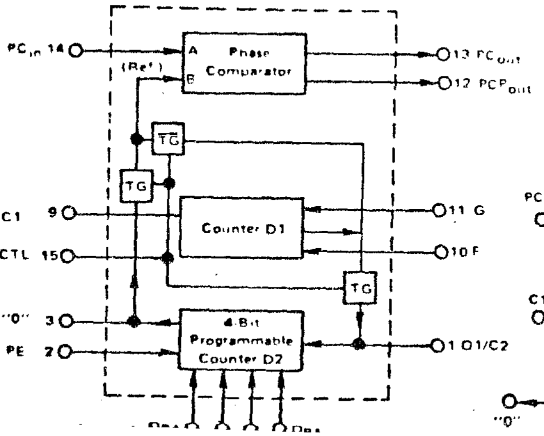
The MC14568B has been designed for use in conjunction with a programmable divide-by-N counter for frequency synthesizers and phase locked loop applications requiring low power dissipation and/or high noise immunity.

- Quiescent Current = 5.0 nA typ/pkg @ 5 Vdc

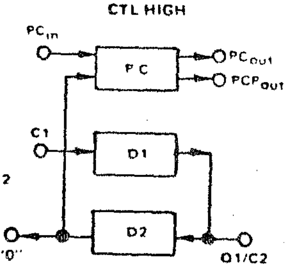
MAXIMUM RATINGS (Voltages referenced to V_{SS})

Rating	Symbol	Value	Unit
DC Supply Voltage	V_{DD}	-0.5 to +18	Vdc
Input Voltage, All Inputs	V_{in}	-0.5 to V_{DD} + 0.5	Vdc
DC Current Drain per Pin	I	10	mAdc
Operating Temperature Range – AL Device CL/CP Device	T_A	-55 to +125 -40 to +85	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C

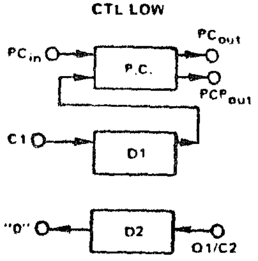
BLOCK DIAGRAM



CTL HIGH



CTL LOW



MC14568B

McMOS MSI

(LOW-POWER COMPLEMENTARY MOS)

PHASE COMPARATOR AND PROGRAMMABLE COUNTERS

L SUFFIX
CERAMIC PACKAGE
CASE 620

P SUFFIX
PLASTIC PACKAGE
CASE 648

ORDERING INFORMATION

MC14XXXB — Suffix Denotes
L Ceramic Package
P Plastic Package
A Extended Operating Temperature Range
C Limited Operating Temperature Range

TRUTH TABLE

F Pin 10	G Pin 11	Division Ratio of Counter D1
0	0	4
0	1	16
1	0	64
1	1	100

The divide-by-zero state on the programmable divide-by-N 4-bit binary counter, D2, is illegal.

OPERATING CHARACTERISTICS

The MC14568B contains a phase comparator, a fixed divider (÷ 4, ÷ 16, ÷ 64, ÷ 100) and a programmable divide-by-N 4-bit counter.

PHASE COMPARATOR

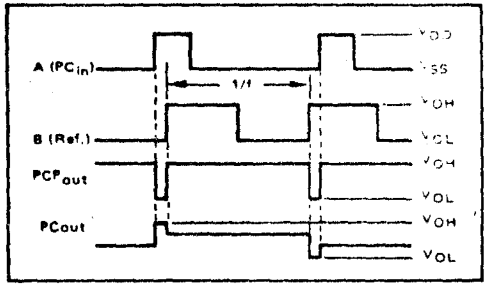
The phase comparator is a positive edge controlled logic circuit. It essentially consists of four flip-flops and an output pair of MOS transistors. Only one of its inputs (PC_{in}, pin 14) is accessible externally. The second is connected to the output of one of the two counters D1 or D2 (see block diagram).

Duty cycles of both input signals (at A and B) need not be taken into consideration since the comparator responds to leading edges only.

If both input signals have identical frequencies but different phases, with signal A (pin 14) leading signal B (Ref.), the comparator output will be high for the time equal to the phase difference.

If signal A lags signal B, the output will be low for the same time. In between, the output will be in a three state condition and the voltage on the capacitor of an RC filter normally connected at this point will have some intermediate value (see Figure 4). When used in a phase locked loop, this value will adjust the Voltage Controlled Oscillator frequency by reducing the phase difference between the reference signal and the divided VCO frequency to zero.

FIGURE 4 – PHASE COMPARATOR WAVEFORMS



If the input signals have different frequenci put signal will be high when signal A has a quency than signal B, and low otherwise.

Under the same conditions of frequency dif output will vary between V_{OH} (or V_{OL}) and mediate value until the frequencies of both equal and their phase difference equal to zer locked condition is obtained.

Capture and lock range will be determined b frequency range. The comparator is provided indicator output, which will stay at logic 1 conditions.

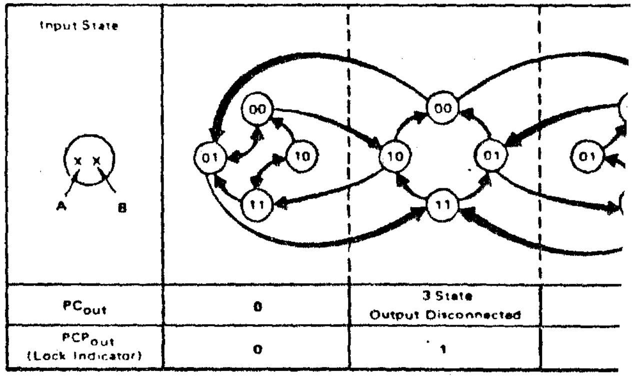
The state diagram (Figure 5) depicts the in transitions. It assumes that only one transitio signal occurs at any time. It shows that a cha output state is always associated with a positiv of either signal. For a negative transition, the c not change state. A positive transition may no output to change; this happens when the s different frequencies.

DIVIDE BY 4, 16, 64 OR 100 COUNTER (D1

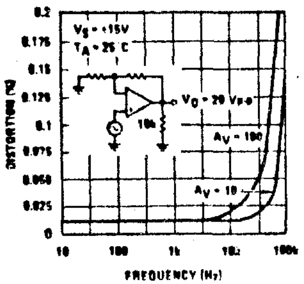
This counter is able to work at an input fr 5 MHz for a V_{DD} value of 10 volts over th temperature range when dividing by 4, 64 an gramming is accomplished by use of inputs F 10 and 11) according to the truth table show ing the Control input (CTL, pin 15) to V_{DD} cading this counter with the programmable counter provided in the same package. I operation is obtained when the Control in nected to V_{SS}.

The different division ratios have been cho erate the reference frequences corresponding nel spacings normally required in frequency applications. For example, with the divisio and a 5 MHz crystal stabilized source a re quency of 50 kHz is supplied to the comp lower division ratios permit operation with lo crystals.

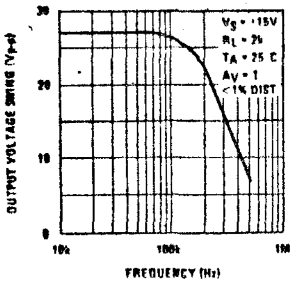
FIGURE 5 – PHASE COMPARATOR STATE DIAGRAM



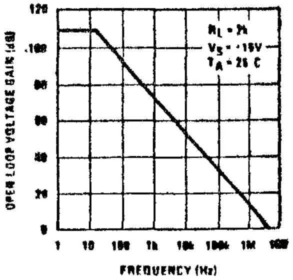
Distortion vs Frequency



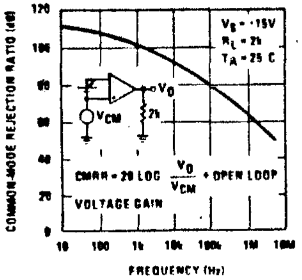
Undistorted Output Voltage Swing



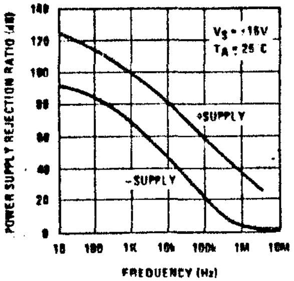
Open Loop Frequency Res



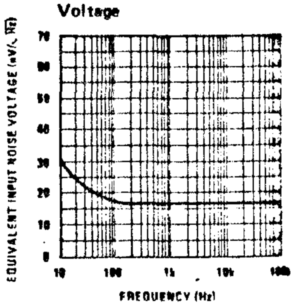
Common-Mode Rejection Ratio



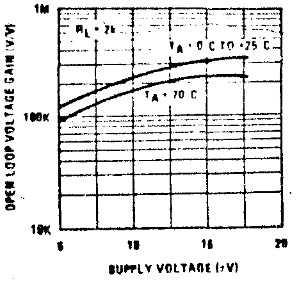
Power Supply Rejection Ratio



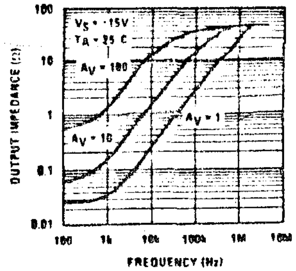
Equivalent Input Noise Voltage



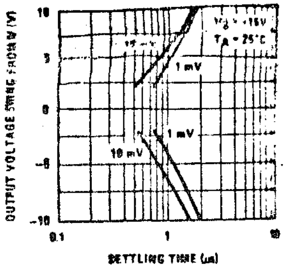
Open Loop Voltage Gain (V/V)



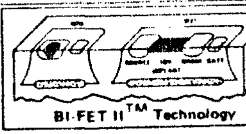
Output Impedance



Inverter Settling Time



National Semiconductor


BI-FET II™ Technology

LF353 Wide Bandwidth Dual JFET Input Operational Amplifier

General Description

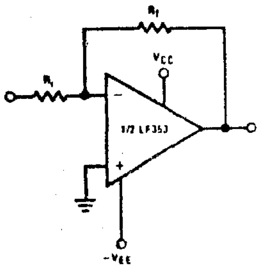
These devices are low cost, high speed, dual JFET input operational amplifiers with an internally trimmed input offset voltage (BI-FET II™ technology). They require low supply current yet maintain a large gain bandwidth product and fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The LF353 is pin compatible with the standard LM1558 allowing designers to immediately upgrade the overall performance of existing LM1558 and LM358 designs.

These amplifiers may be used in applications such as high speed integrators, fast D/A converters, sample and hold circuits and many other circuits requiring low input offset voltage, low input bias current, high input impedance, high slew rate and wide bandwidth. The devices also exhibit low noise and offset voltage drift.

Features

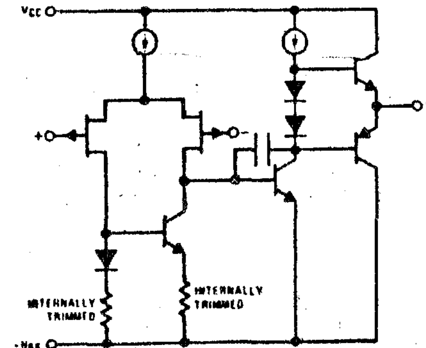
- Internally trimmed offset voltage
- Low input bias current 5
- Low input noise voltage 16 nV
- Low input noise current 0.01 pA
- Wide gain bandwidth 4
- High slew rate 13
- Low supply current 3
- High input impedance 1
- Low total harmonic distortion $A_V = 10$, $R_L = 10k$, $V_O = 20\ V_{p-p}$, BW = 20 Hz–20 kHz <
- Low 1/f noise corner
- Fast settling time to 0.01%

Typical Connection



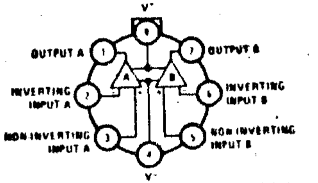
Simplified Schematic

1/2 Dual



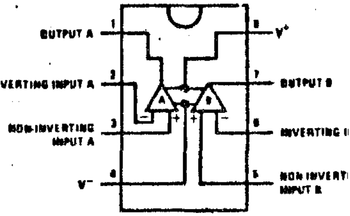
Connection Diagrams

LF353H Metal Can Package (Top View)



Order Number LF353AH or LF353BH
See NS Package H08C

LF353N Dual-In-Line Package (Top Vie



Order Number LF353AN, LF353BN or LF353
See NS Package N08A

Supply Voltage	±18V
Power Dissipation (Note 1)	500 mW
Operating Temperature Range	0°C to +70°C
$T_{j(MAX)}$	115°C
Differential Input Voltage	±30V
Input Voltage Range (Note 2)	±15V
Output Short Circuit Duration (Note 3)	Continuous
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

DC Electrical Characteristics (Note 4)

SYMBOL	PARAMETER	CONDITIONS	LF353A			LF353B			LF353			UN
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{OS}	Input Offset Voltage	R_S = 10 kΩ, T_A = 25°C		1	2		3	5		5	10	
		Over Temperature			4			7			13	
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S = 10 kΩ		10	20		10	30		10		µV
I_{OS}	Input Offset Current	T_j = 25°C, (Notes 4, 5)		25	100		25	100		25	100	
		$T_j \leq 70°C$			2			4			4	
I_B	Input Bias Current	T_j = 25°C, (Notes 4, 5)		50			50	200		50	200	
		$T_j \leq 70°C$			4			8			8	
R_{IN}	Input Resistance	T_j = 25°C		10^{12}			10^{12}			10^{12}		
A_{VOL}	Large Signal Voltage Gain	V_S = ±15V, T_A = 25°C V_O = ±10V, R_L = 2 kΩ	50	100		50	100		25	100		V
		Over Temperature	25			25			15			V
V_O	Output Voltage Swing	V_S = ±15V, R_L = 10 kΩ	±12	±13.5		±12	±13.5		±12	±13.5		
V_{CM}	Input Common-Mode Voltage Range	V_S = ±15V	±11	+15 −12		±11	+15 −12		±11	+15 −12		
CMRR	Common-Mode Rejection Ratio	$R_S \leq 10$ kΩ	80	100		80	100		70	100		
PSRR	Supply Voltage Rejection Ratio	(Note 6)	80	100		80	100		70	100		
I_S	Supply Current			3.6	5.6		3.6	5.6		3.6	6.5	

AC Electrical Characteristics (Note 4)

SYMBOL	PARAMETER	CONDITIONS	LF353A			LF353B			LF353			UN
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
	Amplifier to Amplifier Coupling	T_A = 25°C, f = 1 Hz–20 kHz (Input Referred)		−120			−120			−120		
SR	Slew Rate	V_S = ±15V, T_A = 25°C	10	13			13			13		
GBW	Gain-Bandwidth Product	V_S = ±15V, T_A = 25°C	3	4			4			4		
e_n	Equivalent Input Noise Voltage	T_A = 25°C, R_S = 100Ω, f = 1000 Hz		16			16			16		nV
i_n	Equivalent Input Noise Current	T_j = 25°C, f = 1000 Hz		0.01			0.01			0.01		pA

Note 1: For operating at elevated temperature, the device must be derated based on a thermal resistance of 160°C/W junction to ambient fo the N package, and 150°C/W junction to ambient for the H package.

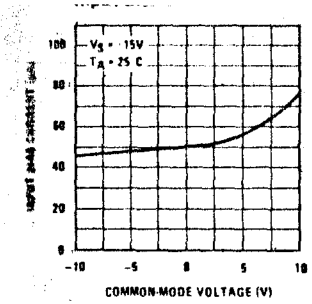
Note 2: Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

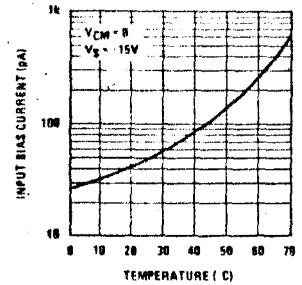
Note 3: The power dissipation limit, however, cannot be exceeded.

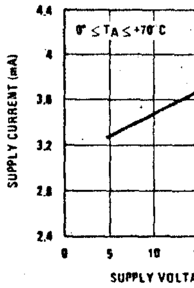
Note 4: These specifications apply for V_S = ±15V and $0°C \leq T_A \leq +70°C$. V_{OS}, I_B and I_{OS} are measured at V_{CM} = 0.

Note 5: The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature T_j. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junctio temperature rises above the ambient temperature as a result of internal power dissipation, P_D. $T_j = T_A + \Theta_{jA} P_D$ where Θ_{jA} is the thermal resis tance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

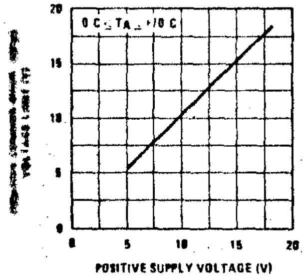
decreasing simultaneously in accordance with



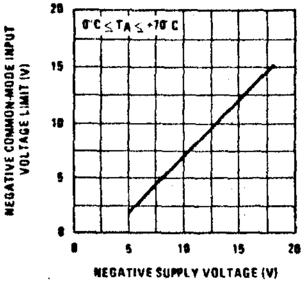




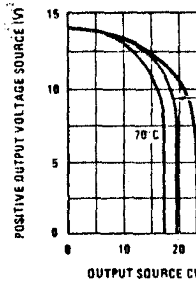
Positive Common-Mode Input Voltage Limit



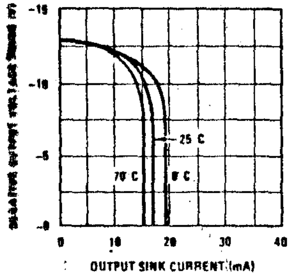
Negative Common-Mode Input Voltage Limit



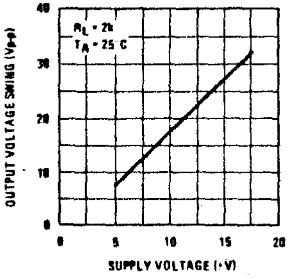
Positive Current



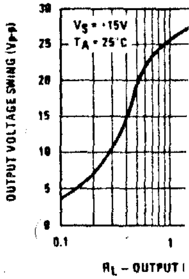
Negative Current Limit



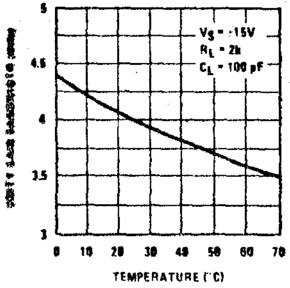
Voltage Swing



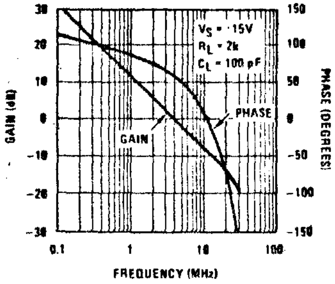
Output Voltage



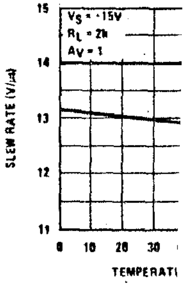
Gain Bandwidth



Bode Plot



Slew Rate



Vierpol Kenngrößen · Two port characteristics

Umgebungstemperatur t_{amb} = 25° C

		Min.	Typ.	Max.	
Emitterschaltung	**BF 230**				
U_{CB} = 10 V, I_C = 1 mA, f = 100 MHz					
Kurzschluß-Eingangsadmittanz	g_{ie}		7,5		mS
	C_{ie}		25		pF
Kurzschluß-Rückwärtssteilheit	$\lvert y_{re} \rvert$		600		µS
	$-\varphi_{re}$		93°		
Kurzschluß-Vorwärtssteilheit	$\lvert y_{fe} \rvert$		31		mS
	$-\varphi_{fe}$		30°		
Kurzschluß-Ausgangsadmittanz	g_{oe}		10		µS
	C_{oe}		1,6		pF
Basisschaltung	**BF 230**				
U_{CB} = 10 V, I_C = 1 mA, f = 100 MHz					
Kurzschluß-Eingangsadmittanz	g_{ib}		33		mS
	$-b_{ib}$		5,7		mS
Kurzschluß-Rückwärtssteilheit	$\lvert y_{rb} \rvert$		480		µS
	$-\varphi_{rb}$		92°		
Kurzschluß-Vorwärtssteilheit	$\lvert y_{fb} \rvert$		31		mS
	$-\varphi_{fb}$		150°		
Kurzschluß-Ausgangsadmittanz	g_{ob}		12		µS
	C_{ob}		1,6		pF

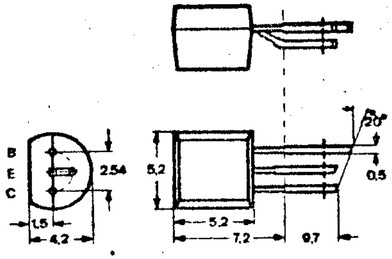
BF 24

Silizium-NPN-Epitaxial-Planar-HF-Transistor für geregelte AM- und FM-Stufen in Emitterschaltung.

Silicon NPN epitaxial planar RF transistor for controlled AM and FM stages in common emitter configuration.

Abmessungen · Dimensions

Maße in mm
M 2:1



Kunststoffgehäu
≈ TO
Gewicht · Weig
max. 0,2

Absolute Grenzdaten · Absolute maximum ratings

Kollektor-Basis-Sperrspannung	U_{CBO}	40	
Kollektor-Emitter-Sperrspannung	U_{CEO}	40	
Emitter-Basis-Sperrspannung	U_{EBO}	4	
Kollektorstrom	I_C	25	m
Basisstrom	I_B	2	m
Gesamtverlustleistung			
$t_{amb} \leqq 45°C$	P_{tot}	300	m
Sperrschichttemperatur	t_j	150	°
Lagerungstemperatur	t_{stg}	−55...+150	°

		Min.	Typ.	Max.	
Wärmewiderstand · Thermal resistance					
Sperrschicht-Umgebung	R_{thJA}			350	°C/W
Statische Kenngrößen · DC characteristics					
Umgebungstemperatur t_{amb} = 25° C					
Kollektorreststrom U_{CB} = 20 V	I_{CBO}			100	nA
Kollektor-Basis-Durchbruchspannung I_C = 10 μA	$U_{(BR)CBO}$	40			V
Kollektor-Emitter-Durchbruchspannung I_C = 2 mA	$U_{(BR)CEO}$ [1]	40			V
Emitter-Basis-Durchbruchspannung I_E = 10 μA	$U_{(BR)EBO}$	4			V
Basis-Emitterspannung U_{CE} = 10 V, I_C = 1 mA	U_{BE}	650	700	740	mV
Kollektor-Basis-Gleichstromverhältnis U_{CE} = 10 V, I_C = 1 mA	h_{FE}	67		220	
Dynamische Kenngrößen · AC characteristics					
Umgebungstemperatur t_{amb} = 25° C					
Transitfrequenz U_{CB} = 10 V, I_C = 1 mA, f = 100 MHz	f_T		430		MHz
Rückwirkungskapazität U_{CB} = 10 V, I_C = 1 mA, f = 0,47 MHz	$C_{üre}$		0,27	0,34	pF
Rauschmaß, Emitterschaltung U_{CB} = 10 V, I_C = 1 mA, G_G = 5 mS, f = 200 kHz	F		1,5	3,5	dB
U_{CB} = 10 V, I_C = 1 mA, Y_G = 6,6 mS − j 3,3 mS, f = 100 MHz	F		1,6		dB
Kurzschluß-Ausgangsleitwert U_{CB} = 10 V, I_C = 1 mA, f = 0,47 MHz	g_{oe}			8,3	μS
f = 10,7 MHz	g_{oe}			10,5	μS
Kollektorstrom für | y_{fe} | max. U_{CB} = 10 V, f = 36 MHz	I_C	10			mA

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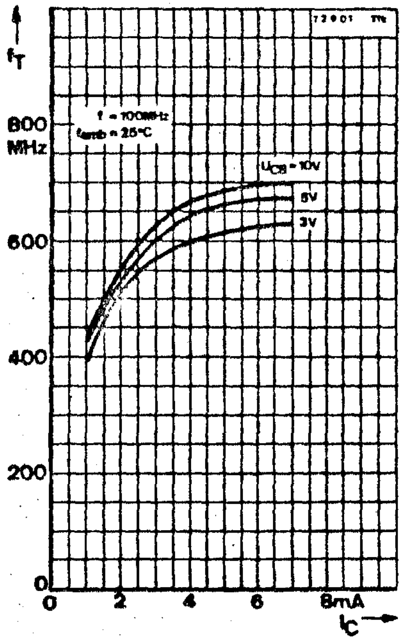
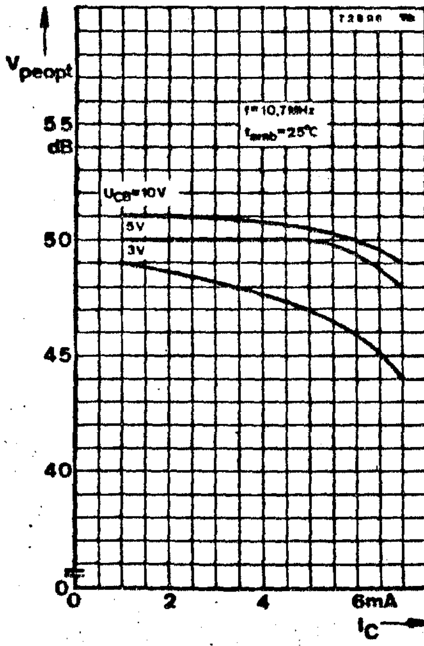
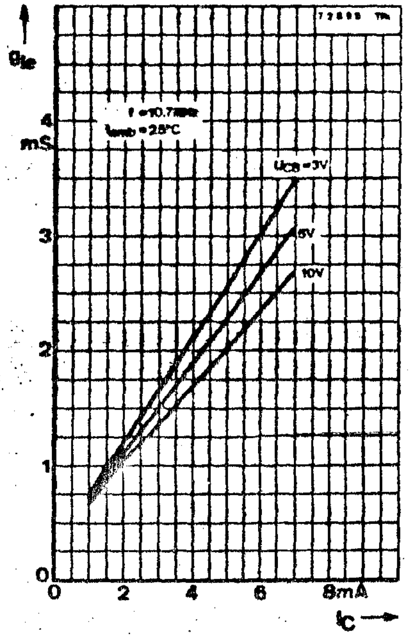
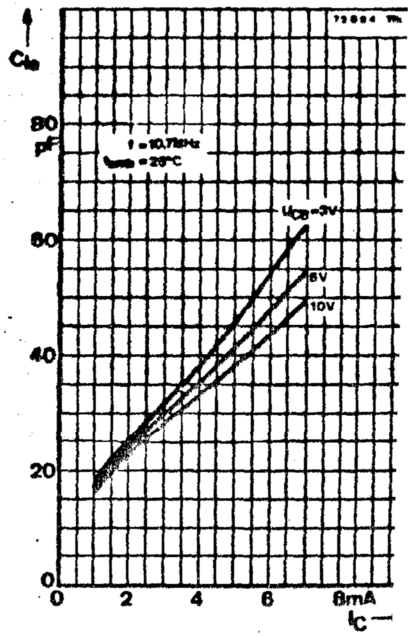
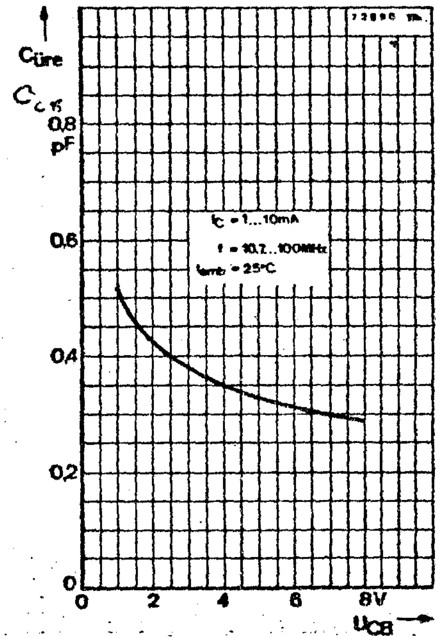
[1] $\frac{t_p}{T}$ = 0,01, t_p = 0,3 ms

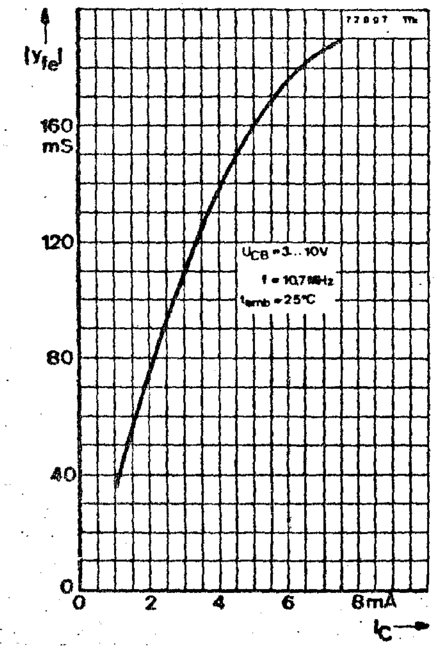


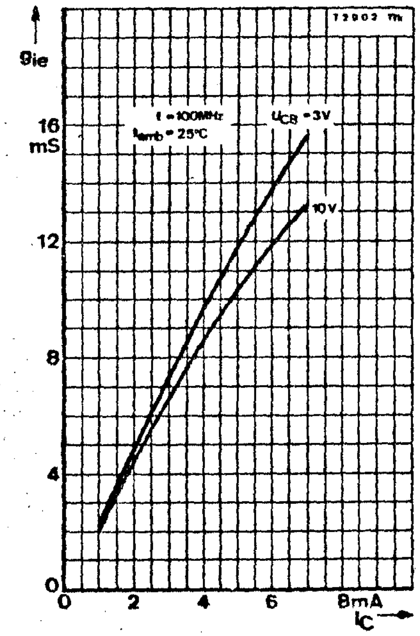


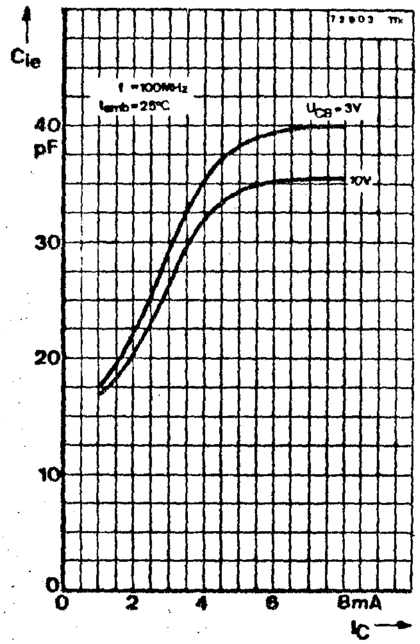


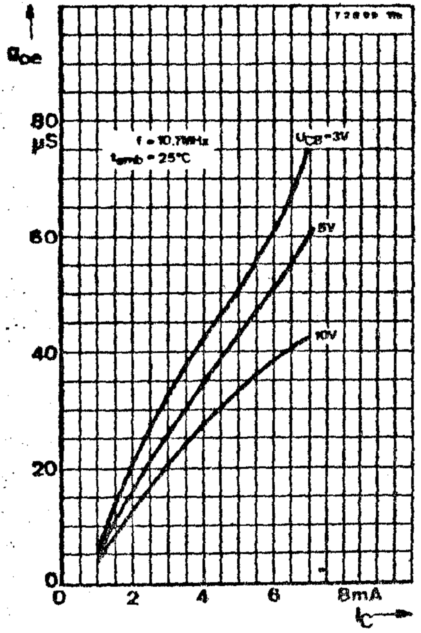


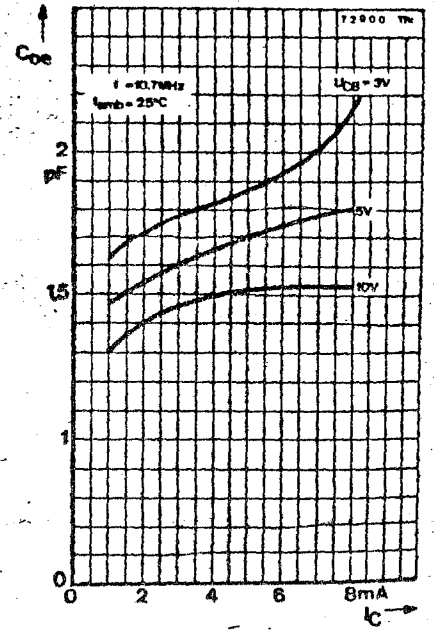

72896 Tfk
Cüre
Ccb
0,8
pF
0,6
0,4
0,2
0
Ic = 1...10mA
f = 10,7...100MHz
tamb = 25°C
0
2
4
6
8V
UCB

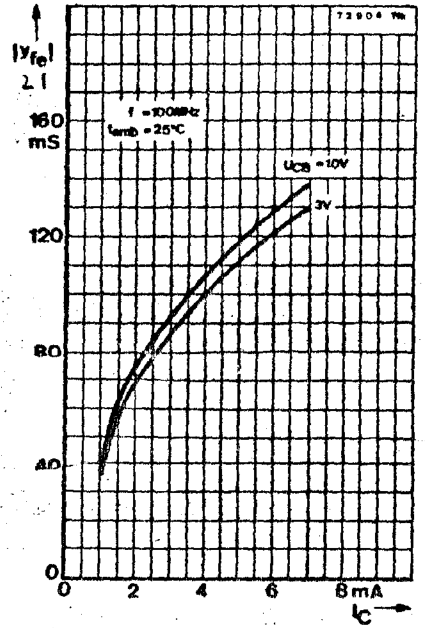

72897 Tfk
|yfe|
160
mS
120
80
40
0
UCB = 3...10V
f = 10,7MHz
tamb = 25°C
0
2
4
6
8mA
IC

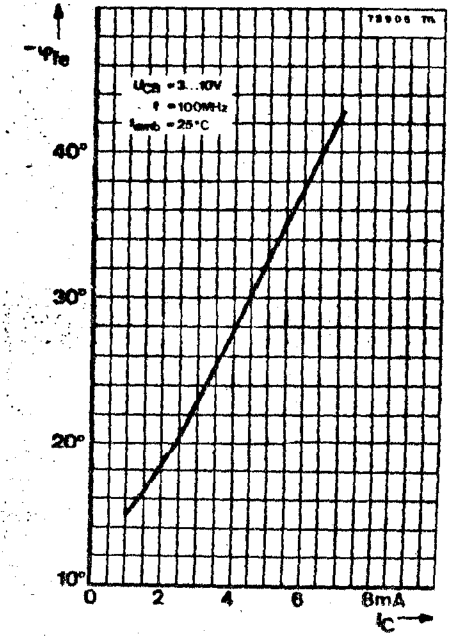

72902 Tfk
gie
16
mS
12
8
4
0
f = 100MHz
tamb = 25°C
UCB = 3V
10V
0
2
4
6
8mA
IC


72903 Tfk
Cie
40
pF
30
20
10
0
f = 100MHz
tamb = 25°C
UCB = 3V
10V
0
2
4
6
8mA
IC


72899 Tfk
goe
80
µS
60
40
20
0
f = 10,7MHz
tamb = 25°C
UCB = 3V
5V
10V
0
2
4
6
8mA
IC


72900 Tfk
Coe
2
pF
1,5
1
0
f = 10,7MHz
tamb = 25°C
UCB = 3V
5V
10V
0
2
4
6
8mA
IC


72904 Tfk
|yfe|
2,1
160
mS
120
80
40
0
f = 100MHz
tamb = 25°C
UCB = 10V
3V
0
2
4
6
8mA
IC


72905 Tfk
-φfe
40°
30°
20°
10°
UCB = 3...10V
f = 100MHz
tamb = 25°C
0
2
4
6
8mA
IC

TYPICAL CHARACTERISTICS

CUTOFF CURRENT
(Each Transistor)

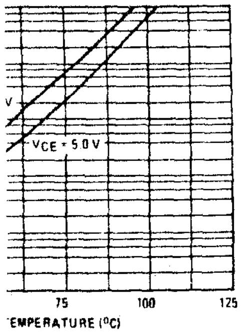
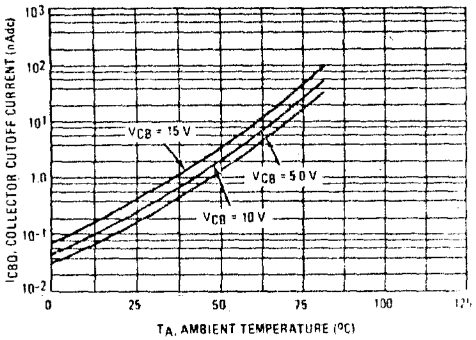


FIGURE 2 – COLLECTOR CUTOFF CURRENT
versus TEMPERATURE (Each Transistor)



CHARACTERISTICS FOR
Q2

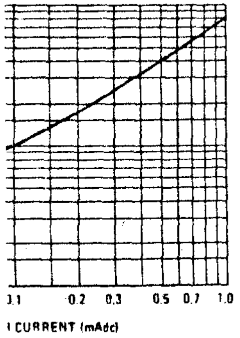


FIGURE 4 – BASE-EMITTER AND INPUT OFFSET VOLTAGE CHARACTERISTICS

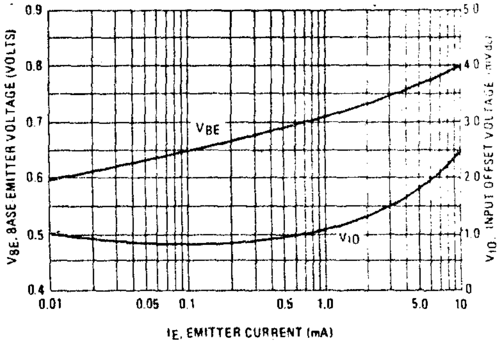
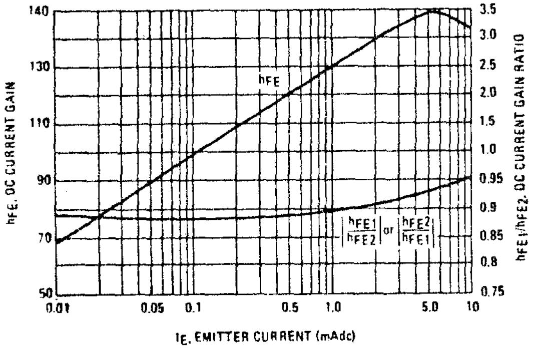


FIGURE 5 – DC CURRENT GAIN



MC3357

Advance Information

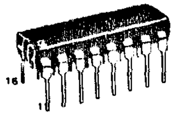
LOW POWER NARROW BAND FM IF

. . . includes Oscillator, Mixer, Limiting Amplifier, Quadrature Discriminator, Active Filter, Squelch, Scan Control, and Mute Switch. The MC3357 is designed for use in FM dual conversion communications equipment.

- Low Drain Current (3.0 mA (Typ) @ V_{CC} = 6.0 Vdc)
- Excellent Sensitivity: Input Limiting Voltage – (-3.0 dB) = 5.0 μV (Typ)
- Low Number of External Parts Required

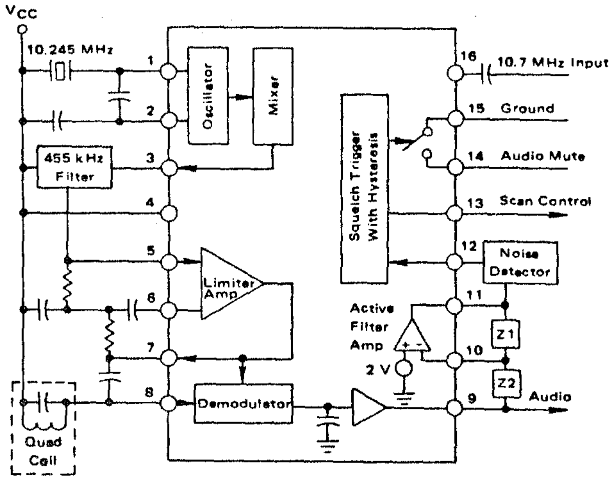
LOW POWER
FM IF

MONOLITHIC SILICON
INTEGRATED CIRCUIT

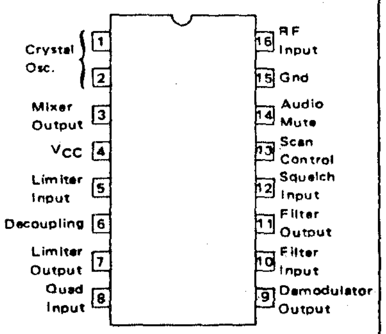


P SUFFIX
PLASTIC PACKAGE
CASE 648

FIGURE 1 – FUNCTIONAL BLOCK DIAGRAM



PIN CONNECTIONS



This is advance information and specifications are subject to change without notice.

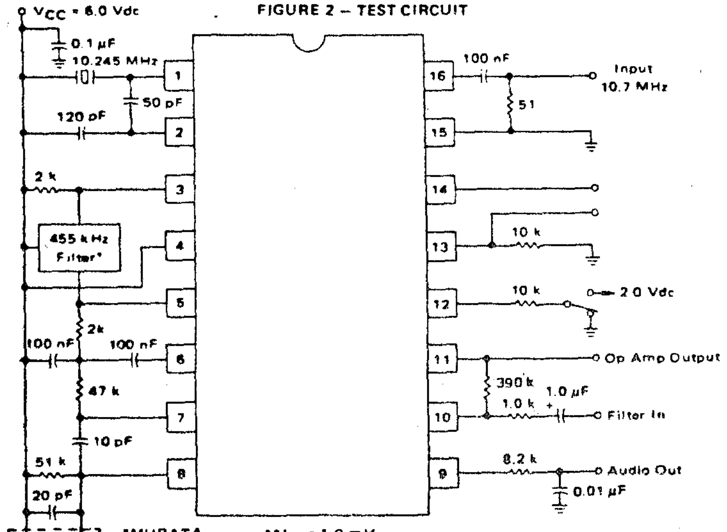
A = 25°C unless otherwise noted)

Rating	Pin	Symbol	Value	Unit
Power Supply Voltage	4	$V_{CC(max)}$	12	Vdc
Operating Supply Voltage Range	4	V_{CC}	4 to 8	Vdc
Detector Input Voltage	8	–	1.0	Vp-p
Input Voltage (V_{CC} > 6.0 Volts)	16	V_{16}	1.0	V_{RMS}
Mute Function	14	V_{14}	-0.5 to 5.0	V_{pk}
Junction Temperature	–	T_J	150	°C
Operating Ambient Temperature Range	–	T_A	–30 to +70	°C
Storage Temperature Range	–	T_{stg}	–65 to +150	°C

LECTRICAL CHARACTERISTICS (V_{CC} = 6.0 Vdc, fo = 10.7 MHz, Δf = ± 3.0 kHz, f_{mod} = 1.0 kHz, T_A = 25°C unless otherw

Characteristic	Pin	Min	Typ	Max	Un
rain Current	4				mA
Squelch Off		–	2.0	–	
Squelch On		–	3.5	5.0	
put Limiting Voltage (–3 dB Limiting)	16	–	5.0	10	µ
etector Output Voltage	9	–	3.0	–	V
etector Output Impedance	–	–	400	–	Ω
ecovered Audio Output Voltage (V_{in} = 10 mV)	9	200	350	–	mV
ilter Gain (10 kHz) (V_{in} = 5 mV)	–	40	46	–	dB
ilter Output Voltage	11	1.8	2.0	2.5	V
igger Hysteresis	–	–	100	–	mV
ute Function Low	14	–	15	50	Ω
ute Function High	14	1.0	10	–	MΩ
can Function Low (Mute Off) (V_{12} = 2 Vdc)	13	–	0	0.5	Vdc
can Function High (Mute On) (V_{12} = Gnd)	13	5.0	–	–	Vdc
ixer Conversion Gain	3	–	20	–	dB
ixer Input Resistance	16	–	3.3	–	kΩ
ixer Input Capacitance	16	–	22	–	pF

FIGURE 2 – TEST CIRCUIT



*MURATA CFU

**Lp = 1.0 mH
Cp = 100 nF

CIRCUIT DESCRIPTION

The MC3357 is a low power FM IF circuit designed primarily for use in voice communication scanning receivers.

The mixer-oscillator combination converts the input frequency (e.g., 10.7 MHz) down to 455 kHz, where, after external bandpass filtering, most of the amplification is done. The audio is recovered using a conventional quadrature FM detector. The absence of an input signal is indicated by the presence of noise above the desired audio frequencies. This "noise band" is monitored by an active filter and a detector. A squelch trigger circuit indicates the presence of noise (or a tone) by an output which can be used to control scanning. At the same time, an internal switch is operated which can be used to mute the audio.

The oscillator is an internally-biased Colpitts type with the collector, base, and emitter connections at pins 4, 1, and 2 respectively. A crystal can be used in place of the usual coil.

The mixer is doubly-balanced to reduce spurious responses. The input impedance at pin 16 is set by a 3 kΩ internal biasing resistor and has low capacitance, allowing the circuit to be preceded by a crystal filter. The collector output at pin 3 must be dc connected to B+, below which it can swing 0.5 V.

After suitable bandpass filtering (ceramic or LC) the signal goes to the input of a five stage limiter at pin 5. The output of the limiter at pin 7 drives a multiplier, bot internally directly, and externally through a quadratur coil, to detect the FM. The output at pin 7 is also used t supply dc feedback to pin 5. The other side of the fir limiter stage is decoupled at pin 6.

The recovered audio is partially filtered, then buffere giving an impedance of around 400 Ω at pin 9. The sign still requires de-emphasis, volume control and furth amplification before driving a loudspeaker.

A simple inverting op amp is provided with an outp at pin 11 providing dc bias (externally) to the input pin 10 which is referred internally to 2 V. A filter can made with external impedance elements to discrimina between frequencies. With an external AM detector t filtered audio signal can be checked for the presence noise above the normal audio band, or a tone signal. T information is applied to pin 12.

An external positive bias to pin 12 sets up the sque trigger circuit such that pin 13 is low at an impeda level of around 60 kΩ, and the audio mute (pin 14 open circuit. If pin 12 is pulled down to 0.7 V by noise or tone detector, pin 13 will rise to approxima 0.5 Vdc below supply where it can support a load cur of around 500 µA and pin 14 is internally short-circu to ground. There is 100 mV of hysteresis at pin 1 prevent jitter. Audio muting is accomplished by connec pin 14 to a high-impedance ground-reference point ir audio path between pin 9 and the audio amplifier.

BIBLIOGRAPHY

1) CRC Critical Reviews in Biomedical Engineering. February 1982
2) Medical Electronics IEE Monographs 1-6 Hill and Watson
3) Biomedical Telemetry. R.Stuart Mckay. John Wiley Sons 1970
4) Design of Microprocessor based Medical Instrumentation,Webster PHI
5) Biomedical Instrumentation and Measurements L.Cromwell Prentice-Hall, Inc,
6) VHF/UHF Manual, RSGB, 1976
7) Communication Circuits: Analysis and Design Clarke-Hess, 1971
8) Motorola RF Data Manual Motorola Inc, 1980
9) Linear Applications Handbook National Semiconductor, 1980
10) Electronic Circuits C.Holt, J.Wiley and Sons, 1980
11) Introduction to Microprocessors, Leventhal Prentice Hall, 1978
12) Communication Systems, Carlson, Mc Graw Hill
13) Circuit Design for Audio, AM, FM and T.V. Texas Instruments Electronic Series, 1967
14) CRC Handbook of engineering in Medicine and Biology V1,1980
15) Designing with phase locked loop ciruits