DESIGN AND CONSTRUCTION OF ULTRASOUND DETECTOR

AS APPLIED TO LEAK/FAULT DETECTION

BY

GANA D. DAVID
REG. No. 98/6974EE.

A PROJECT REPORT SUBMITTED FOR THE AWARD OF BACHELOR OF ENGINEERING DEGREE (B.Eng) IN ELECTRICAL AND COMPUTER ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE.

NOVEMBER 2004

DECLARATION

I hereby declare that this project was carried out by me GANA DANGANA DAVID, 98/6974EE of Electrical and Computer Engineering Department, Federal University Of Technology, under the supervision of ENGR. M.S AHMED.

David 07/12/04

....

GANA D.DAVID

CERTIFICATION

This is to certify that this project work was carried out by GANA D. DAVID, 98/6974EE for the award of bachelor of Engineering in Electrical and Computer Engineering, Federal University of Technology Minna.

ENGR M. S AHMED 7/12/04

Supervisor Sign/Date

ENGR M.D ABDULLAHI ....

Head of Department Sign/ Date

....

EXTERNAL EXAMINER Sign/ Date

DEDICATION

This work is dedicated to God Almighty for his love, strength, protection, provision, wisdom and mercy towards me.

ACKNOWLEDGEMENT

I want to appreciate the Lord Almighty for keeping me throughout my degree program and also for the wisdom, knowledge, understanding and success he gave me during my academic pursuit.

I also want to thank Mr. Paul M Jiya and my mother Mrs Elizabeth K Gana for their moral and financial support. Special appreciation also goes to my cousins Mr. Dauda Jiya, Mr. Suleman Jiya, Mr. Yakubu Jiya, Dr. Samuel Jiya, Miss Grace Jiya, Miss Comfort(Dama queen) Jiya, and Miss Mana Jiya and also to my brother Samson Gana; I love you all.

I wish to express my profound appreciation to my project supervisor ENGR M.S Ahmed who spared part of his precious time to attend to me, made suggestions, criticisms and guided me throughout my project work. Also, my thanks go to my Head of Department ENGR M.D Abdullahi and the entire staff of the Department for their support and contributions to my success here.

I also want to express my appreciation to Press unit FCS FUT Minna, you are a true family, I love you all. I must not forget to thank my uncle my Gideon Gana.

Finally, I want to say a big thank you to my friends for being there for me through thick and thin

God bless you all.

GANA D DAVID

ABSTRACT.

This Project focuses on the determination of integrity of working parts in industries, transportation and domestic appliances using ultrasound detector.

Most engines, high-pressure systems such as steam boilers and gas pipelines produce ultrasonic sound when there is a fault in them. The ultrasound detector is aimed at detecting these sounds, which enables the location and isolation of the fault, or leakage that may not be visible to the human eye.

This report presents detailed information on the utilization of this technology that includes ultrasonic transducer, heterodyne mixer and audio amplifier to produce the best sound and give a relatively high sensitivity.

It is hoped that further research would be done to improve the effectiveness of the technology.

TABLE OF CONTENT

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Whenever we turn on a domestic appliance, fill a petrol tank, travel by air, sea or rail; we rely directly or indirectly on some equipment or structure, working reliably under stress. For example, most electricity generation involves high pressure steam boilers, gas transported to the users through high pressure pipelines, most modern forms of transportation rely on the integrity of components subjected to large and rapidly varying stress.

Ultrasonic detection is one of the most useful technologies of airborne ultrasound. The instruments cover a broad range of plant operation, yet they are simple enough that almost anyone involved with equipment performance can use then with relatively small training.

Some of the common plant applications of ultrasonic detection are: leak detection in pressure and vacuum systems. (i.e. boilers, heat exchangers, condensers and vacuum furnaces), bearing inspection, detection of corona in switch-gear, compressor valve analysis, integrity of seals in tanks and pipes e.t.c.

All operating equipment and most leakage problems produce a broad range of sound. The high frequency components of these sounds are utilized for the detection of these leaks and defects.

Since leaks cost money, affect product quality and can wreak havoc, ultrasonic detection can often locate the problem to enable appropriate action to be taken.

An ultrasound detector is basically made up of an input transducer, which is responsible for converting the ultrasonic sound into electrical signal, a gain amplifier, that amplifies the electrical signal, a tone decoder, heterodyne mixer which converts the high frequency signal to audible range and an amplifier which drives the audio out put.

1.1 LITERATURE REVIEW

Until about 19 0, ultrasonic waves were little more than scientific theory. After the successful development of the piezoelectric transducers, they were used in sonar to detect the presence of submerged submarines by detecting reflected ultrasonic waves from an ultrasonic source.

Its use as fault detector was first developed in the early 1970's as a laboratory hand held tool with one transmitter transducer and one receiver transducer. In the early days of development, it was regarded as a potentially very accurate sizing method for cracks which were either readily visible or had been found by conventional ultrasonic techniques. This technique had been confined to the inspection of small components and seemed therefore to be mainly of academic interest at that time. However, with the decision of the central Electricity Generating Board (CEGB) to plan for a pressurized water reactor at sizewel. coupled with public concern about the integrity of the pressure vessel, it became urgent to demonstrate that there were techniques available, which could ensure that vessels were free from defects.

Results from the wielding institute study encouraged the development of this technique, with which cook carried out large-scale comparative trials (1972).

The earlier technique used was pulse echo. The problem with this technique is that it is based on assumption that echoes come from planer features, which are suitably angled to give a specula reflection back to the transducer. Hanes et al (1982) however highlighted the failing of various national standard inspection codes to give necessary confidence in detecting disoriented defects.

Not until recently was it discovered that most operating equipment and most leakage problems produce a broad range of sound. The high frequency ultrasonic component of these sounds are extremely short wave in nature and short wave signal tend to be fairly directional. It is therefore necessary to isolate these signals from the background noises and detect their exact location.

Airborne ultrasound instruments often referred to as " ultrasonic translators" provide information in two ways: qualitatively due to ability to hear ultrasounds through noise isolating headphones and quantitatively via incremental readings on a meter. For the purpose of this work, the signal will be detected using only the quantitative method. This is accomplished by electronic process called "heterodyning" which accurately converts the ultrasounds served by the instrument into the audible range where users can hear and recognize them.

1.2 PROJECT OBJECTIVE AND MOTIVE

The motive of this project work is to design and construct a simple lightweight device that will detect leaks and faults in electrical and mechanical systems. Some of the major objectives of this work include: -

1 To design and construct a simple low-cost device that will aid the detection of leaks and faults.

2 To ease preventive and predictive maintenance

3 To be able to determine the integrity of working parts so as to prevent failures

4 To be able to detect very small faults which may not be visible to the human eye.

1.3 APPLICATIONS

Some of its applications include: -

LEAK DETECTION

The reason ultrasound is so versatile that it detects sound of a leak when fluid (liquid or gas) leaks, it moves from the high pressure side through the leak site, were it expands rapidly and reduces a turbulent flow. This turbulent flow has strong ultrasonic component.

ELECTRICAL APPLICATIONS

Although theoretically ultrasonic detection can be used in low, medium and high voltage systems, most of the applications tend to be in medium and high voltage systems. Electrical applications include testing of insulators, cables, switchgear, bus bars, relays, contractors and junction boxes. In substations, components such as insulators transformers and bushings may be tested. Ultrasonic sound is often used for evaluation at voltages exceeding 2000 volts. Also, on lower voltages, loose connections can be revealed in junction boxes.

1.4 PROJECT LAYOUT.

Chapter one introduces the project and reviews related developments to the design and construction of ultrasound detector, the motive as well as the objectives of the work.

Chapter two basically deals with the theories related to the system, the design and its analysis.

Chapter three deals with the construction and testing of the project

The results obtained after testing are discussed and observations made in chapter four. Also, the conclusion and recommendations are made as it affects the entire project work. It also includes problems faced and solutions, areas for further improvement and conclusion.

CHAPTER TWO

SYSTEM DESIGN & ANALYSIS

2.1 INTRODUCTION

In the design of ultrasonic detector, a stage-by-stage design approach was used. The design was done in stages – from the input stage to the output stage because the output of a particular stage feeds or serves as the input to the next stage.

The design stages include

1. The input transducer (piezoelectric transducer)
2. The gain amplifier
3. The tone decoder
4. The heterodyne mixer
5. Audio Amplifier
6. Output transducer (headphone)

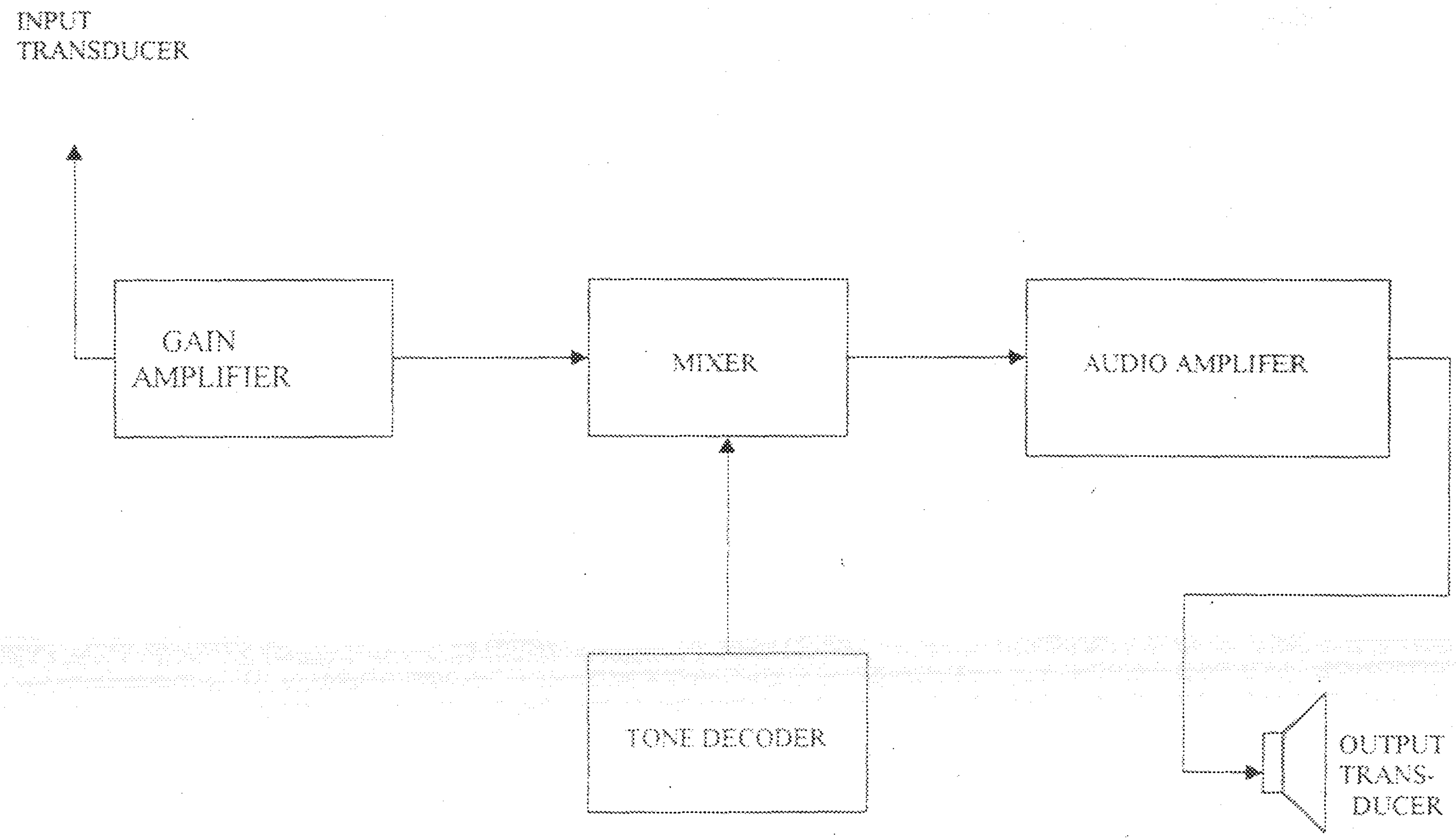

fig 2.1 BLOCK DIAGRAM OF ULTRASONIC SOUND DETECTOR

2.2 THE ULTRASONIC TRANSDUCER

The ultrasonic transducer is a device that transforms ultrasound at about 20khz to electrical signals.

The development of piezoelectric materials has resulted in considerable extension of the use of the ultrasonic principle for many applications such as flow, thickness, and fault detection and intruder detection systems. In general, an ultrasonic transducer system consists of 2 piezoelectric Crystals, both in contact with the medium to be measured, but separated from each other by a short distance.

The circuit for this project uses a piezo tweeter as an ultrasonic microphone. A piezo tweeter acts like a microphone and indeed is one except that it receives sound waves at very high frequencies of about 20kHz, which is above the audible range of humans.

The advantages of the transducer over other sensors include ,

1 Ultrasonic sensors are not affected by dust, dirt or high moisture environments.

2 Resistant to external disturbances such as vibration infrared radiation, ambient noise e.t.c.

3 Solid state units have virtually unlimited, maintenance free lifespan.

The following were considered in the choice of an appropriate transducer.

- Sensitivity: - to enable detection of weak signals and provide sufficient output for the Next stage.

- Frequency response and resonant frequency

- Operating range:- For good resolution and maintain Chosen range requirements.

- Environmental Compatibility:-Temperature range, corrosive Fluid, size and mounting Restriction.

- Exploitation and durability:- To determine if the device will last

Exploitation and durability:- To determine if the device will lasLong under the required working conditions and its electrical and mechanical suitability for its functions.

2.3 THE GAIN AMPLIFIER

The received signal from the transducer has to be amplified and demodulated for onward transfer to the next stage.

For the design of this amplifier stage, two transistors were connected in cascade (cascaded amplification). Using the common emitter configuration. The output of the first stage feeds the second stage. The common-emitter configuration has among others the following characteristics:-

1 A high current gain (β) (50- 300)

2 A very high voltage gain

3 Low input resistance.

Now, 2 stages of amplification was used because often, the voltage amplification, power gain or frequency response obtained with a single stage of amplification is insufficient to meet the requirements of the circuit.

The overall voltage gain of the cascaded amplifier is equal to the product of the gain of individual stages:

$$A_v = A_{v1} \times A_{v2} \times A_{v3} \ldots\ldots\ldots$$

However, in decibel, the gain of the multistage amplifier will be the sum of the decibel gain of each stage

$$G = G_1 + G_2 + G_3$$

While power gain

$$G_P = 10 \log_{10} A_P \text{ (db)}$$

2.3.1 COUPLING

All amplifiers need some coupling network. The resistance – capacitance (RC) coupling method was used. The connecting link between the two stages is the capacitor. The function of the RC coupling used is to pass the signal from one stage to another and to block unwanted signals from passing to the nest stage.

When operational, the input signal from the transducer is amplified by **Q1** (Fig 2.1 below), it is then phase reversed due to the CE configuration. The amplified output of **Q1** then appears across R2, and the output is coupled to the input of **Q2** by the coupling capacitor C2. The signal at the base of Q2 is further amplified and its phase is again reversed. The final output can be obtained at the collector of **Q2**.

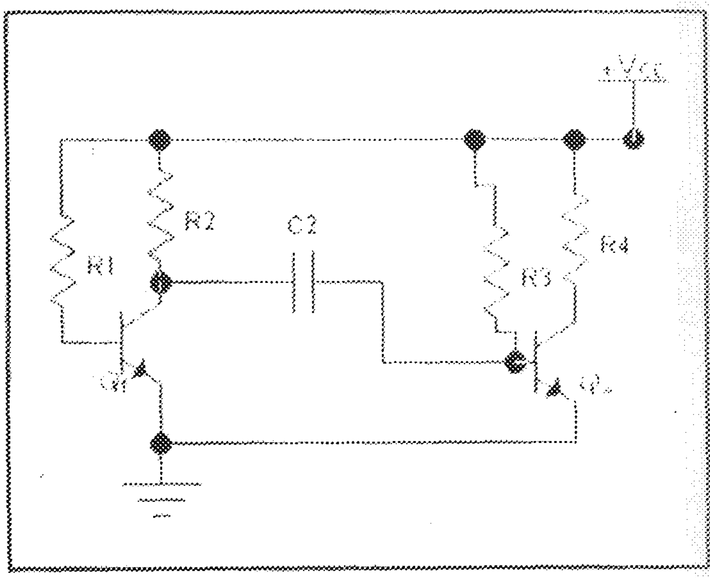

FIG 2.1

For the first stage of the amplification using an NPN transistor, the base is the driving element. The E/B junction is forward biased by VBB and C/B junction is reversed biased by V_{cc}

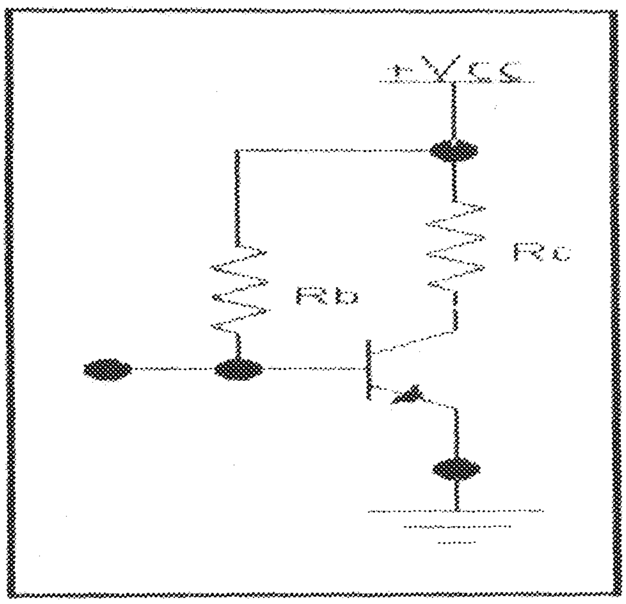

FIG 2.2

The D.C equation is given by :

$I_B = 2\ V_{BB}/R_B$ ---neglecting V_{BE}

$I_C = \beta I_B$ AND $V_{CE} = V_{CC} - I_C R_C$

2.4 THE TONE DECODER

The tone decoder is an AF/RF amplifier. It decodes the ultrasound detected by the transducer to sound wave at a very high frequency.

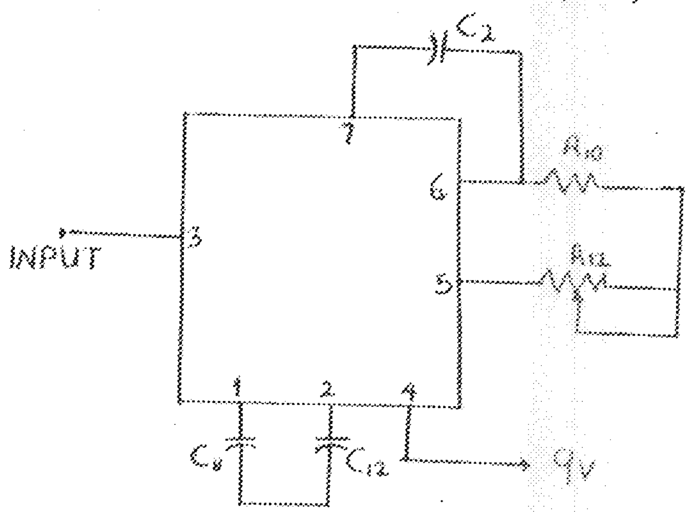

FIG 2.3

The frequency f_o is given by

$$F_o = \frac{1}{1.1 \times C_4 x (R_{10} + R_{12})}$$

$$= \frac{1}{1.1 X 0.0022 X\ 10\text{-}6 x (4.7 + (0\text{-}50)) X 10^3}$$

$= 88 - 7.5KHz$

The output signal from the tone decoder combines with that from the gain amplifier and fed into the mixer.

2.5 MIXER

The frequency conversion can be achieved by utilising the heterodyne principle. For this purpose, amplified signal is "mixed" in a mixer with the signal produced by the local oscillator. The process of combining the two signals of different frequencies in order to obtain a signal of new frequency is called heterodyning. A JFET was used in design of this circuit with the gate serving as input for the two signals.

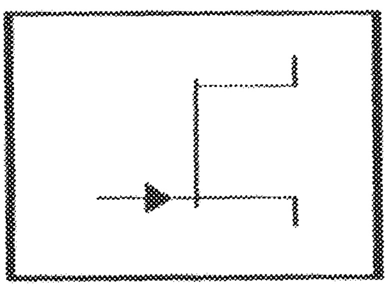

FIG 2.4

The advantage of this is that the IF amplifier cascade which has a fixed input frequency regardless of that of the received signal can be designed more easily for improved selectivity.

The mixer utilizes an N - channel JFET. The JFET has the following notations.

Source. --- The terminal through which the majority of the couriers enter

Drain --- The terminal through which majority of carriers leave the bar

Gate: - These are two internally connected heavily doped impunity regions, which form two NP junctions.

The JFET configuration in the design was the common drain configuration. In the common drain circuit, the load resistance is in series with the source terminal. The input signal is applied to the gate and the output is taken out from the source.

The use of JFET has among other advantages

1 High input impedance

2 Small size

3 Ruggedness

4 High frequency response

5 Low noise

The voltage gain A, is approximated to be 1

2.6 AUDIO AMPLIFIER

The function of the audio amplifier in this project is to amplify the level of the alternating voltage converted from the audio frequency level to a level that can effectively drive the headphone. It is however necessary to match the amplifiers output impedance and the impedance of the headphone in order ensure maximum power transfer.

The audio amplifier used is an operational amplifier (Lm 386) IC fig 2.6 below shows the pin connection of the Operational Amplifier. The output is a high level signal compared to its input.

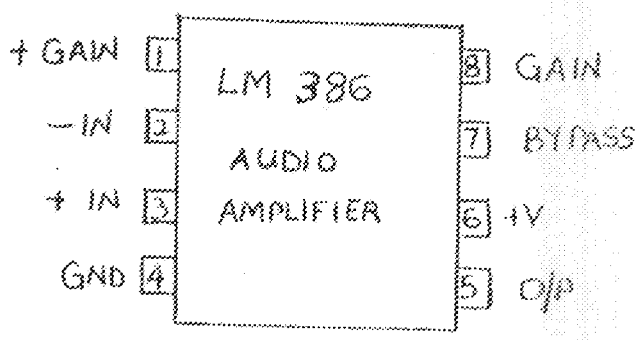

Fig 2.6

The parameters of the audio power amplifier are: -

Input resistance	50KΩ
Operating supply voltage	9V
Voltage gain	26db
Input bias current	250nA
Input voltage	±0.4V

Output power 0.73W

The gain is internally set to 20 to keep the external count low. The inputs are ground referenced while the output is automatically biased to one half of the supply voltage.

2.7 HEADPHONES

In selecting the headphone to be used, the following were considered:-

1 That the headphone had no box resonance and hence produce less noise

2 Acoustic advantage over speakers of not exciting room resonance thus giving the listener a more accurate sense of acoustics.

The headphone is considered a good device for listening because of its portability and privacy. The design utilizes a relatively high sensitive headphone.

Technical specifications

Sensitivity	111 db @ 1 KHz 1 V
Input capability	70mW

Nominal impedance 32Ω

Frequency response 20 – 20,000 Hz

2.8 POWER SUPPLY

The power supply for this circuit is a 9V D.C source

It utilizes a full bridge diode rectifier circuit and a voltage regulator.

The rectifier converts the a.c. input into a pulsating waveform with both d.c and a.c components.

When V_i is positive, diodes D_1 and D_2 conducts. The other two diodes conduct on the next half cycle.

2.8.1 FILTERS

The a.c. ripple in the output of a rectifier is smoothed out by a filter circuit. A capacitor- input filter was used to achieve this.

2.8.2 VOLTAGE REGULATOR

The series type linear regulator was used in the design. The regulator (9V regulator) converts the D.C signal to a steady 9v supply.

CHAPTER THREE

CONSTRUCTION OF ULTRASOUND DETECTOR

3.1 DETAILED CIRCUIT DIAGRAM

Fig 3.1 shows the complete circuit diagram of ultrasound detector.

3.2 MATRIX BOARD LAYOUT

The components were properly laid out on the board so as to enable easy fault identification in the case of any maintenance or repair. The dimension of each component was taken into consideration to prevent overcrowding of components within a particular space or point on the vero board.

A single vero board was used for the construction of the ultrasound detector.

3.3 CONSTRUCTION

ULTRASONIC SOUND RECEIVER

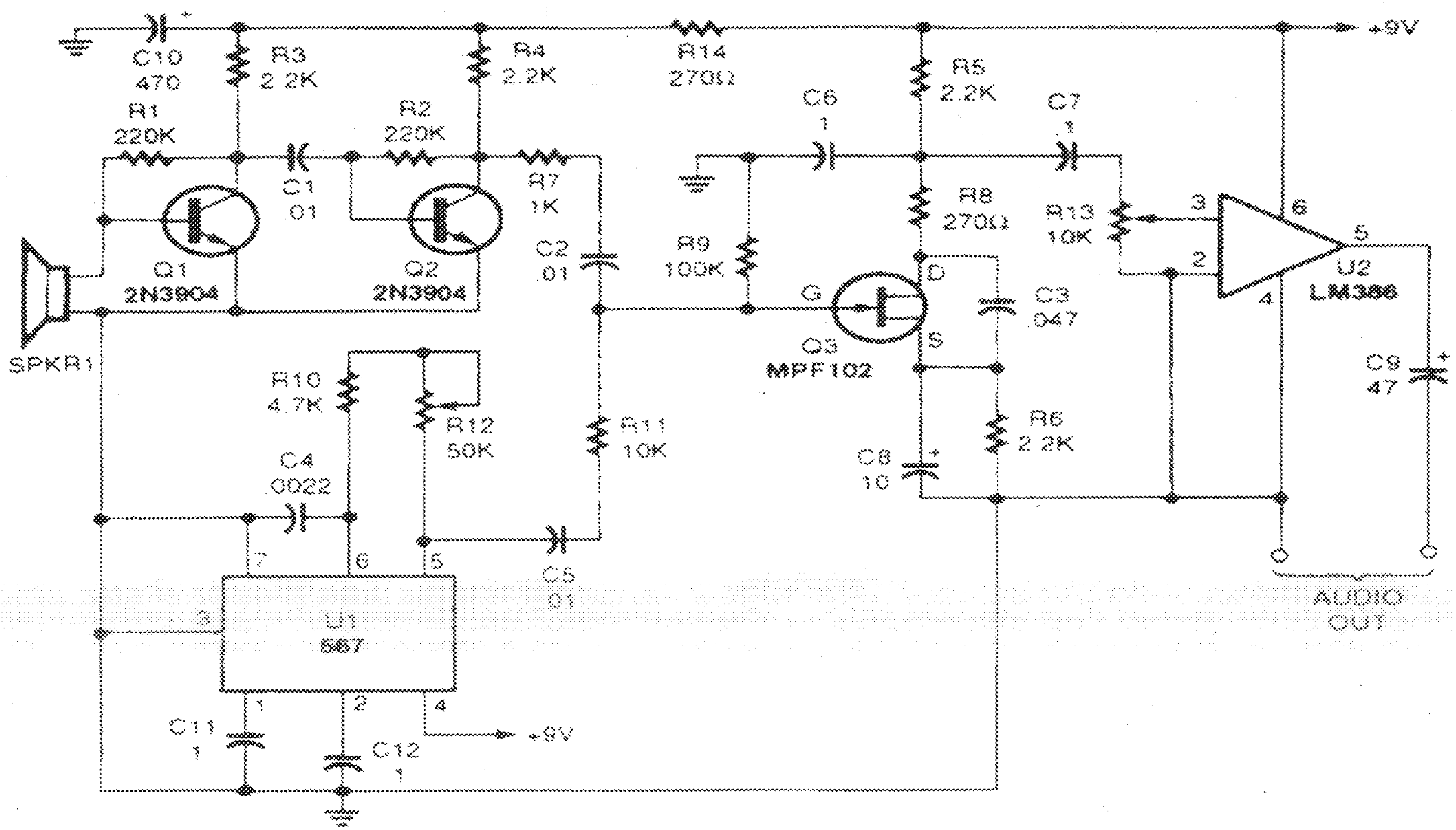

fig. 3-1

The compounds were laid on the vero board with the pins pushed through the hole and the soldered. The protruding excess pins were cut off using a small cutter to avoid bridging of the components. The Soldering was carefully done to avoid bridging two conducting points. For I.C. connections, I.C sockets were used so that any faulty I.C could be replaced easily without having to de-solder and re-solder. Connecting wires were also used to joint separated nodes.

The following were considered while soldering

A it was ensured that the solder formed into a smooth paddle rather than a round ball.

B All excess lead were removed from the board to avoid bridging of the components

C All components were properly placed on the board before soldering so as to avoid any open circuit.

D The solder bridges formed were also broken with the soldering iron.

3.4 CASING CONSTRUCTION

The casing was constructed using a thin metal sheet. The dimension of the casing is about 16 cm X 10cm and a height of about 3.5 cm. This dimension chosen was made a little wider than the board so that the board can sit conveniently and also to allow other parts of the design like the transformer to sit properly

CHAPTER FOUR

TESING, RESULTS AND DISCUSSION OF RESULTS

4.1 INTRODUCTION

The entire work was visually inspected before it was tested to ensure that everything was in the right place

4.2 THE POWER SECTION

The power section was first of all tested to ensure that the output voltage does not exceed the 9v required. Using a multimeter to measure the voltage across the terminal of the voltage regulator, the output voltage was measured to be 8.88 v. which is very close to the desired input voltage.

4.3 THE ULTRASOUND DETECTOR

Several tests were conducted using this equipment. The first test to be conducted was done using an ultrasound generator circuit. The out gave a crackling sound on the headphone. Another test was conducted on the valve of a car tyre. The sound on the headphone remained constant after the first tyre was tested, but on moving to the second tyre, a faint rushing sound was heard on the headphone indicating that the valve was leaking. Subsequent test on other tyres gave negative results. It was also observed that the closer the probe is to the leak site, the louder the signal.

As for electrical systems, a scan through a distribution box did not result in any change in the sound output. However, a scan though an extension box with several plugs plugged into it gave a crackling sound. This sound was different from the sound obtained when the box was unplugged from the mains supply indicating that there was a problem with the contacts of the equipments and that of the box.

By comparing the sound quality among similar equipment, the problem sound tended to be quite different and enabled the determination of a fault.

4.4 CONCLUSION AND RECOMMENDATION

PROBLEMS FACED AND SOLUTIONS

Several problems were encountered during the design and constriction of the system. Some of them include:

1. Non-availability of some of the components. The 220k Ohms resistor was very difficult to get. After several enquiries, I had to look for scraped electronic boards where I was able to find one. This was however time consuming. Another important component that was difficult to find was the ultrasonic transducer, which delayed the work.

(ii) The power supply source was limited by the power cord for outdoor application. Because the power was from an A.C. source, extension cables were needed for outdoor testing of car tyres.

(iii) When testing the equipment, there was interference from RF signal sources. This made the detection of ultrasound difficult in their presence. The variable resistor connected to the tone decoder was varied until the signals were eliminated.

(iv) Another problem encountered was during the testing of electrical systems. The extremely dangerous voltages made testing of such systems a little more difficult. To address this, the probe was not brought too close to the electrical lines to avoid contact and electrocution

4.5 AREAS FOR FURTHER IMPOVEMENT.

Since technology is dynamic and seeks to make life less difficult, I will recommend that the following improvements be made.

1 The system should be interfaced with a computer so that results can be studied easily and accurate determination of faults be made.

2 That the sensitivity of the system be improved on so that minute faults can be easily detected.

3 The system should be motorized so that it can climb to places that might be too high or dangerous for humans and also to ensure that the entire system is scanned through.

4 The design of the power system should be based on battery so that it can be easily used outdoors and in remote areas where source of power is not readily available.

4.6 CONCLUSION

The design and construction of this project was not without its highs and lows. But for persistence and constant effort, the aim of the project was achieved and it is a thing of pride for me, my supervisor and the entire department as it is the first of its kind in Federal University of Technology, Minna.

It is hoped that further research would be done to improve the efficiency of the system.

REFRENCES

1 Gregory B.A. (1981).

An introduction to electrical instrumentation and measurement systems.

Macmillan Pg. 272

2 Charles worth J.P. and Temple J.A.G. (1989).

Engineering applications of ultrasonic time of flight diffraction

Research studies press Ltd. Pg. 3-5

3 The new encyclopaedia Britannica (1982).

Encyclopedia Britamnica Inc. Vol. 18 P.g 840

4 Theraja B.L. and Theraja A.K. (1999).

A textbook of Electrical Technology

S. Chand and Company Ltd. Pg 1823 - 1854

5 Adediran Y.A. (1997).

Telecommunications principles systems

Finom associates, P.g 88 - 98

6 Horowitz Paul and Hill Winfield (1995),

The art of electronics

Cambridge university press. page 91, 316, 909

7 Ian Sinclair R. (1993),

Audio Hi-Fi Handbook

Bulterworth – Heineman. p g. 613 – 615

8 Holf Charles A.

Electronic circuits: Digital and analogue pg 768

9 WWW. uesystems. Com.