CO335 ELECTRONIC DESIGN 2

ULTRASONIC LEVEL DETECTOR

PROJECT BY : Glenn Trigg

PROPOSED BY : Glenn Trigg

SUPERVISED BY : Mr. F.Payne

SYNOPSIS

This project report is a full discussion on the design project carried out during the year. The contents include ; Alternative design techniques , design calculations , test figures , circuit board layouts , circuit diagrams & other drawings , operating & maintenance instructions and data sheets.

CONTENTS

INTRODUCTION

The application for this design was originally discovered in a farming environment, in which two situations arose where there was a need for determining the level of a substance in a container. The first situation was one where an auger was used to transfer grain from a silo to the hopper of a grain crusher (see fig.1). In this case, the auger filled the hopper faster than the crusher could empty it. So during crushing, someone had to be present all the time to switch the auger off when the hopper was full and to turn the auger on when the hopper was nearly empty. Clearly, this is not a very efficient use of man hours as most of the time he is doing nothing, waiting for the hopper to fill or empty, hence the design for a device that will do the same job as the man, allowing him to put the time to better use.

The second situation is fundamentally the same except the substance is different and in a slightly different environment. Here the substance is milk and the container is being fed via a pump from a vat (see fig.2). The container is being used as an intermediate storage container and is emptied by gravity into milk bottles. In this case the flow of milk out of the container is intermittent and so the same need applies for a device to turn the pump on and off as the container fills and empties.

The general requirements for a unit to do this job would be:

- A reasonable range. say 5cm to 2m
- The response time need not be very fast, say less than 1 sec.
- Some simple precaution against false triggering would be desirable although not absolutely neccesary.

DESIGN	SITUATION

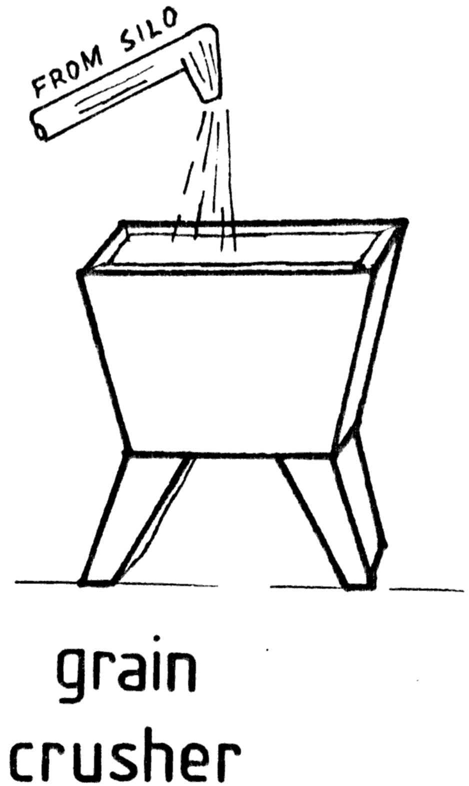


Figure 1

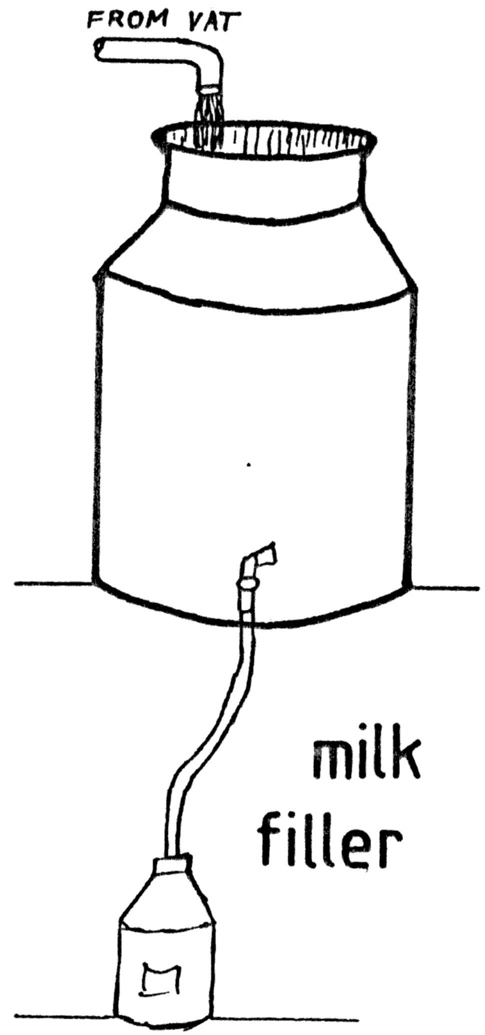


Figure 2

SPECIFICATIONS

Taking into account the general requirements, the specifications would be ;

DISTANCE RANGE	: 0.05 - 2 Meters.
SAMPLING RATE	: 10 samples/second.
RESOLUTION ACCURACY	: +/- 2 cm.
RESPONSE TIME	: <1 sec.
ERROR HANDLING	: Need 6 pulses beyond threshold to cause corrective action.

DESIGN APPROACH

One of the initial considerations to the design problem was a light sensing device. This was quickly rejected because the environment in the grain crushing romm is very dusty. This means that during crushing there would be much fine dust floating in the air that would reduce the light reaching the sensor, and over a period of time the sensor would get covered with a layer of dust.

An imersion type of device was also considered but found to be potentially unsatisfactory. This is solely due to the health regulations concerning milk for human consumption. The regulations state that milk may only contact with stainless steel or plastic, also the health inspectors are very particular about cleanliness (ie bacteria levels) so it was decided that it would be better and save trouble in the long run to design a device that doesn't contact with the substances to be measured.

On that note, a capacitive loading type of solution was considered but also rejected as it would be too difficult to produce a unit that would be universal and having easily setable upper & lower levels.

That left the ultrasonic solution. This solution is simple enough in concept, to time an ultrasonic wave being reflected of the surface of the substance, but still does have inherent problems. The dusty environment of the grain crusher means the transducers will have to be covered to stop them filling with dust. This can be done without really affecting the operation. Probably the main consideration for this solution was that of the grain scattering the ultrasonic wave. A single grain is too small to reflect any significant amount of the wave so the unit will have to 'see' the grain surface as a solid surface that is quite rough. This being the case it seemed safe to assume that the surface scattering can be overcome by increasing the gain of the unit. Another consideration was that of transducer directivity. It is important that the reflected pulse does come from the surface being measured and that

that pulse is received before any other reflected pulses. From a look at transducer data sheets it was found that there are transducers that are direct enough for this application. This eliminates the need to use horns or transducer arrays which would be too bulky for this application. The only other consideration was that of the speed of sound in air. This does change with temperature but the change in response time from one extreme to the other (0^{o} to 40^{o}) is still very much less than the specified response time of 1 second (ie 0.16s) at the longest specified distance.

So of all the different possible solutions, the ultrasonic solution was the best one for this particular situation.

DESIGN CALCULATIONS

BASIC THEORY

The theory of operation for the ultrasonic solution is this : First send an ultrasonic wave pulse and at the same time start a counter or timer. When the reflected pulse is received, stop the counter and compare that representation of the elapsed time with a predetermined value corresponding to the time taken for a pulse to be received from either the upper or lower triggering level. The comparison is that the time taken is shorter than the preset value for the upper level or that the time taken is greater than the preset value for the lower level. If the time taken is outside the desired threshold then a divide by six must be clocked to provide the error trap specified earlier.

It can be seen that the design can be split into two main blocks, the ultrasonic transmit/receive (transceive) section and the count-compare-decide- ÷6 section. The second part , due to the nature of the operations involved, is more easily realized using digital components. So the two parts will be called the ultrasinic transceiver section and the digital section.(see block diagram fig.3)

We will now look at each section in detail.

ULTRASONIC TRANSCEIVER

For this section, it was decided to use an integrated circuit manufactured by National Semiconductor, a LM1812 Ultrasonic Transceiver chip. This chip does both the transmitting and receiving and has noise reject circuitry built in as well. (see fig.4)

To determine the frequency of operation for both transmitting and receiving, an L-C tank is used where the frequency , $f = \frac{1}{2\pi LC}$. In this case the frequency of operation is 40KHz. This is a very common frequency for ultrasonic use in air and the most common transducers are available for this frequency.

So , $40KHz = \frac{1}{2\pi LC}$, as the inductor must be wound , choose a reasonable value for L. Say L=10mH.

BLOCK DIAGRAM

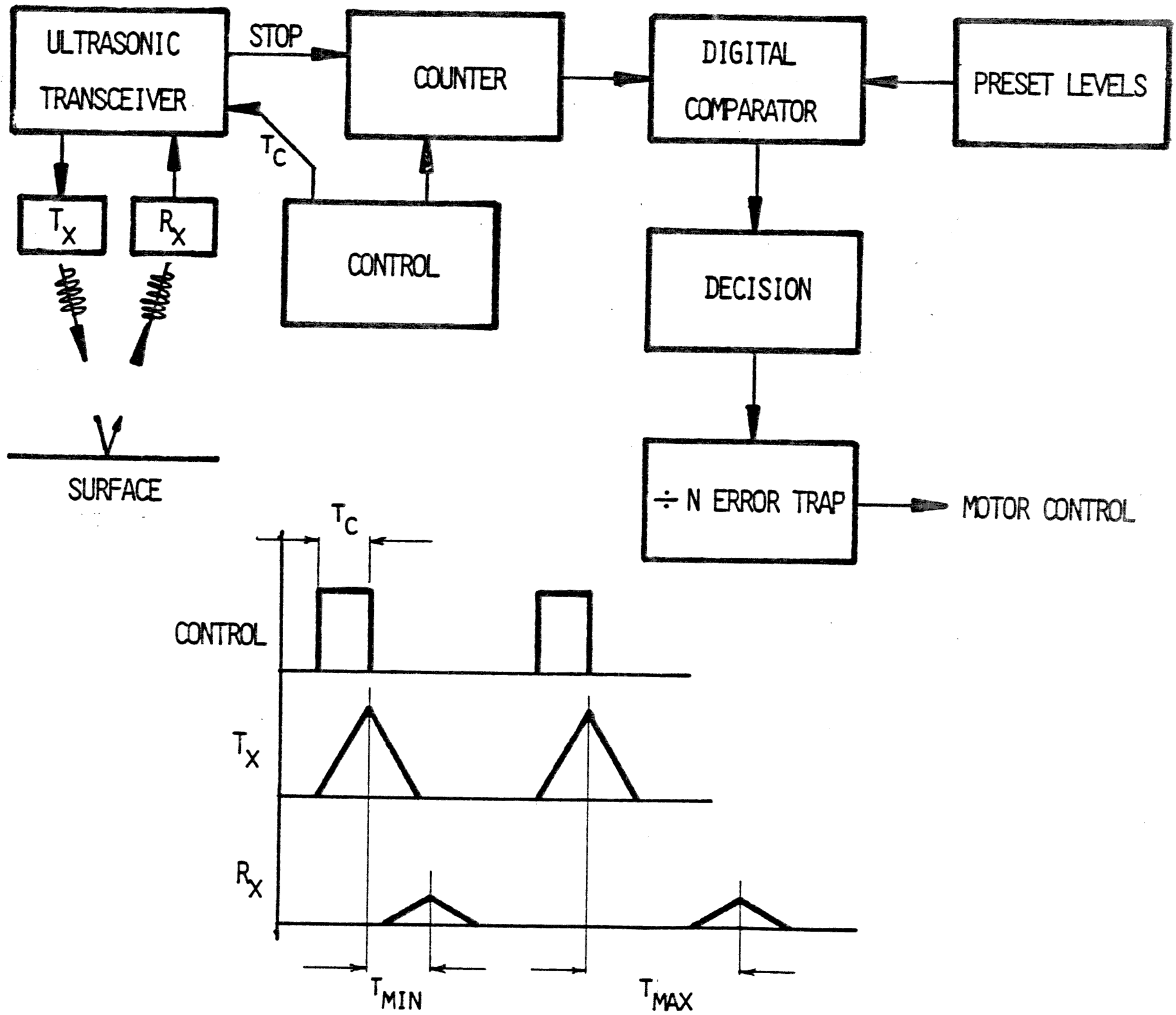


Figure 3

ULTRASONIC TRANSCEIVER

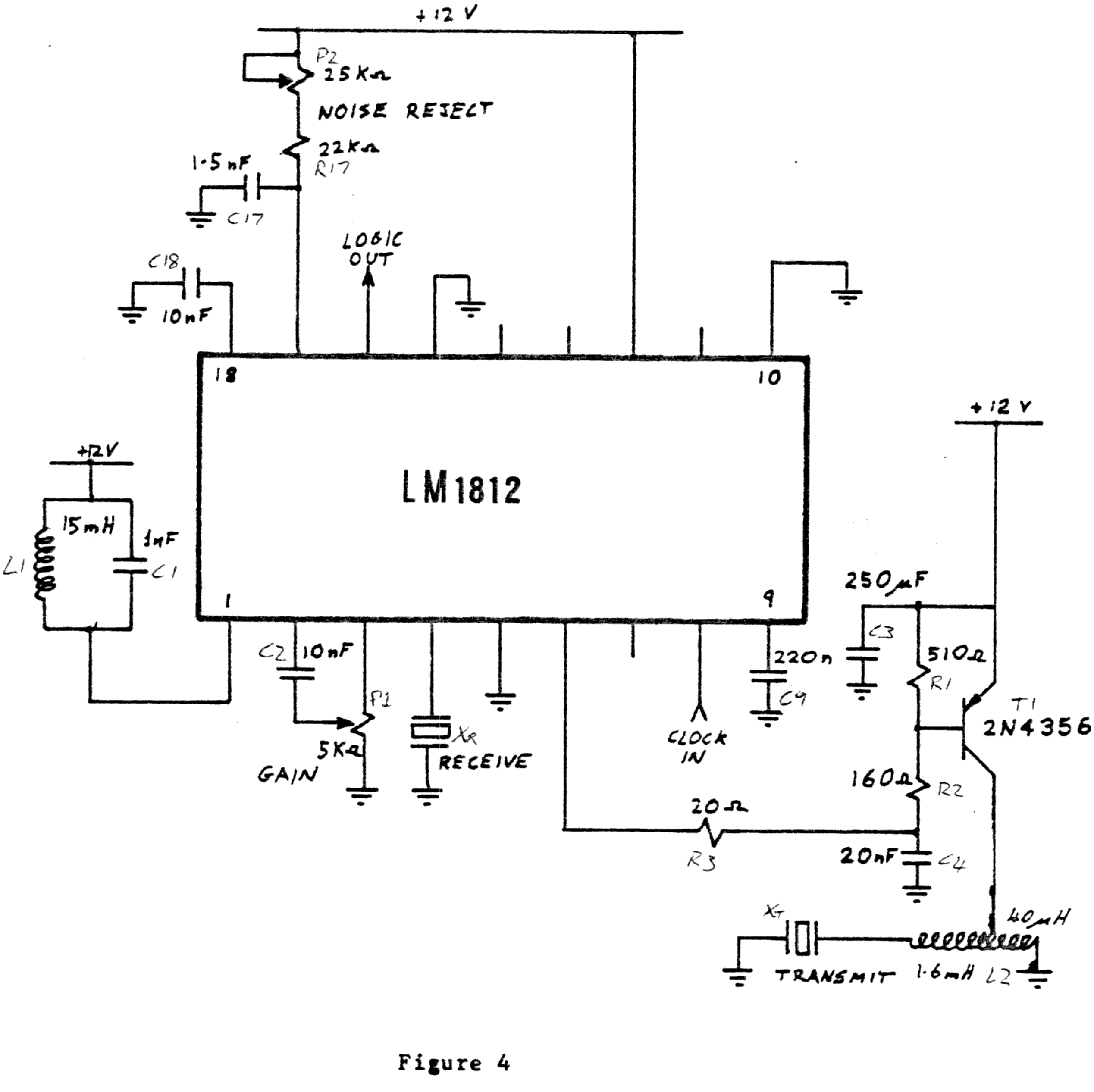


Figure 4

therefore $C = \frac{1}{10m(2\pi 40K)^2}$

$= 1.58$ nF.

As the potcores used have an adjustable core , a nominal value of capacitance (1.5 nF) can be used.

When the LM1812 is in transmit mode, which is acheived by taking pin 8 high, a number of 1µS pulses appear at pin 6 (active low) at the frequency determined by the L-C tank for as long as pin 8 is high. As this chip was primarily designed for a sonar system (ie operation in water) it is recomended that 5µs pulses should be used for operation in air. In the data on the LM1812, the circuitry is given to stretch the 1µs pulses to 5µs so there was no need to redesign that part of the circuitry after verifying that it would in fact do the required job.

Having achieved the 5µs pulses at 40KHz the next step was to design the transformer that drives the transmit transducer. The first part of the transformer, ie from the transistor collector to ground, must be such that a maximum current of 1A is produced in the 5µs pulse time. So the time constant of the inductor & series resistor must be equal to 5µs.

ie $T = 5\mu s = \frac{L}{8}$.

$L = 40\mu H$.

The other part of the transformer must be resonant with the transducer capacitance which is approximately 10nF (from data).

so $L_2 = \frac{1}{w^2 . 10nF}$ $\quad w = 2\pi . 40KHz$.

$= 1.583$ mH.

This gives a turns ratio of 6.3 .

Before going on to the receiver , we will look at the actual potcore designs of both inductors. Both were designed with the use of the nomograph published in ETI Circuit Techniques Vol.1. For the inductor in the L-C tank an inductance of 10mH was chosen. It was decided to use a Philips P18/11 type core for size considerations. Looking at the maximum turns table, a wire size of B&S 30 was chosen, giving maximum turns of 197.

Going to the nomograph, a core type of AL-250 was needed.

A similar technique was used for the transformer only the choice of wire size was limited due to the current flowing in the primary. Due to that factor the larger core size , P26/16 had to be used. Given the turns ratio of 6.3 and the inductances of 40μH & 1.58mH, the following parameters were used;

CORE TYPE : AL-400

N° OF TURNS : 73 tapped at 10 turns.

WIRE SIZE : B&S 22.

Returning to the receiver section of the LM1812. After the transmitter has stopped (pin 8 low) the receiver is not turned on for a short time to allow the transmit transducer to stop ringing. This delay is achieved by C9 and a graph of receiver delay vs C9 is given in the data. For this design C9 = 220nF. After the delay the reflected pulse is received at pin 4, amplified at pin 3 and then passes through P1 & C2 to a second amplifier. P1 provides a manual gain control and C2 is just D.C. decoupling between the amplifiers. The second amplifier is also connected to the L-C tank and provides high gain at the tank frequency ie 40KHz. The amplified signal then passes through an integrator to filter out the unwanted noise. This integrator has a time constant of approximately 10% to 50% of the transmit time. After the integration delay, if the signal is still present, pins 16 and 14 go low until the integrator is reset. This happens when the incoming signal drops too low and after a delay introduced by C18.

Pin 16 is the logic output , pin 14 provides a power amplifier stage for driving a display. Only pin 16 is used in this design.

The control for this section is provided by a 555 timer. To achieve a minimum distance of 5cm, the time taken for a pulse to return to the unit is 290.95μs (the speed of sound in air is 343.7 m/s). To allow for transducer ringing a transmit pulse of 250μs was decided on. To achieve 10 samples/second (specified) these pulses must be 100ms apart.

Using the standard astable configuration of the 555 (see fig.5), a diode must be used across R2 to achieve such a small duty cycle.

So Charge time = 0.693R1.C = 250μs

Discharge time = 0.693.R2.C = 99.75ms

Choosing C = 100nF ,

R1 = 7.2 KΩ

R2 = 1.44 MΩ

These values would be achieved by using trimpots in series with 6.8 KΩ and 1 MΩ resistors.

DIGITAL SECTION

For the digital section, a counter is needed where the digital output is a representation of the time elapsed for the pulse to return. The frequency of operation of the counter determines the accuracy of the device. To achieve the specified resolution accuracy of +/- 2cm, which is the time it takes for sound to travel 4cm (the sound pulses have to travel there and back).

So $t = \frac{.04}{343.7} = 116.38\mu s.$

Therefore choose a clock frequency of 10KHz which will provide an accuracy of (100μs.343.7)/2 = 1.72cm. Using an 8-bit counter, the maximum range that can be measured before the counter resets is 4.38m which is quite a large margin.

The 10KHz clock is made from another 555 timer i.c. As the counter is positive edge triggered the duty cycle is not important.

So choosing C = 100pF and R1 = 1KΩ

R2 = ((1.44/Cf)-R1)/2 where f = 10KHz.

= 719.5 KΩ

Use a 680 KΩ resistor with a trimpot in series to enable the frequency to be adjustable.

The rest of this part of the design is largely a matter of selecting the logic blocks and connecting them together. As 12V is

DIGITAL SECTION

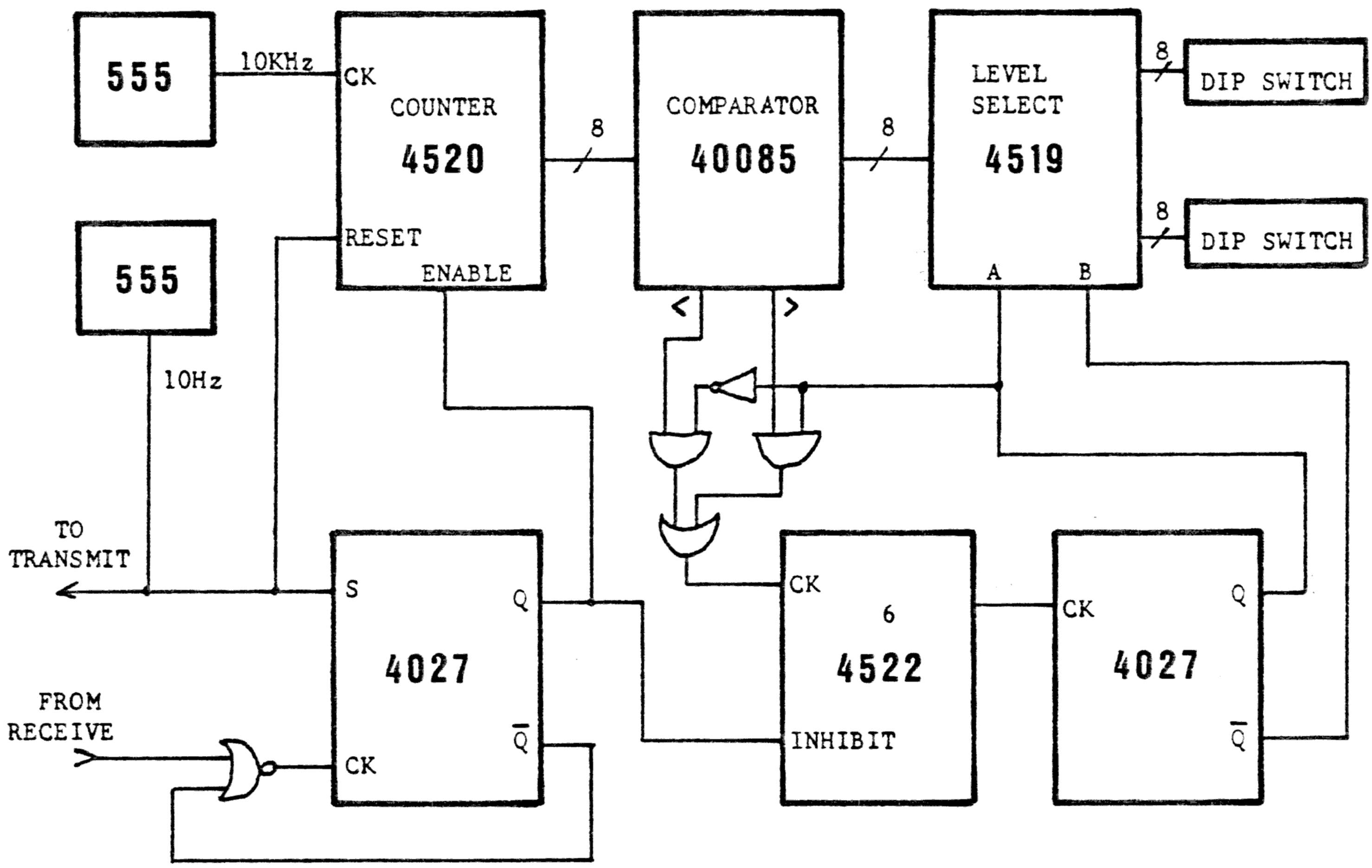


Figure 6

used for the LM1812, CMOS logic was chosen. Also the noise immunity of CMOS is an advantage over TTL or other logic types.

The counter chosen was a 4520 which is really two 4-bit counters in the one package connected together to make one 8-bit counter. The comparitor was made from two separate 4-bit magnitude comparitors (40085) that are cascadeable to make one 8-bit comparitor with <,>&= outputs. Two 4-bit AND/OR selectors (4519) were used to switch between the two preset levels. The preset devices originally considered were binary thumbwheel switches, due to their ease of operation, but they were considered too expensive. So 8-bit D.I.P. switches were used instead. These are not as easy to set, as the user would need to know binary, but as the saving in cost was considerable, a table of settings and corresponding distances could be drawn up for the user.

The ÷6 error trap was realized using a 4522 ÷N i.c. To keep the response time under 1sec. and to keep the circuitry fairly simple on the 4522 the ÷6 number was chosen. The two other devices shown on fig.6 and the simple logic gates shown were also needed and their operation is best described in the description of the whole digital section.

When the 250µs pulse is sent to the transceiver, it is also used to reset the counter and to set the first flip-flop. This makes Q high which enables the counter and inhibits the ÷6. The counter only starts counting after the transmit pulse goes low. The first low pulse from the receiver then clocks the flip-flop and isolates it from other pulses. This causes Q to go low which disables the counter and uninhibits the ÷6. During this time the comparitor is continually comparing its two inputs (as it is not synchronous). When Q goes low, if the clock pin of the ÷6 is high, the low-going inhibit pin will cause a count. The effect of the clock being high means that the count is outside the threshold.

After 6 such pulses the output of the ÷6 will clock the second flip-flop. The output of this flip-flop does three things. The Q output is the motor control, so after every clock the motor changes state (on or off). The same output also causes the threshold select circuitry to change (ie> to < etc.). Both Q and $\overline{Q}$ are used by the 4519 to select the other D.I.P. switch level select package.

The process then continues, alternating between the two threshold levels. There is no need for power-up resets or manual reset as the circuit will sort itself out after one cycle.

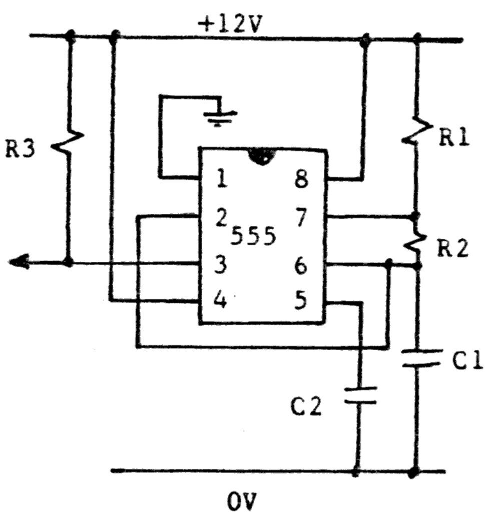


Figure 5

BASIC ASTABLE CONFIGURATION

TEST REPORT

After the circuit was built and made operational,the following test figures were measured;

MAXIMUM DISTANCE : 2.07m.

MINIMUM DISTANCE : 6cm.

RESPONSE TIME : <1sec

CURRENT DRAWN : 82mA.

These values were measured with one layer of Glad Wrap over each transducer and bouncing the pulses off cardboard.

The minimum distance was not quite achieved. It may be possible to achieve this by reducing the blanking capacitor C9 but the value obtained is still quite reasonable so it was decided to leave it as it is. The clock waveforms were set up as accurately as possible with a CRO.

COMPONENT LIST

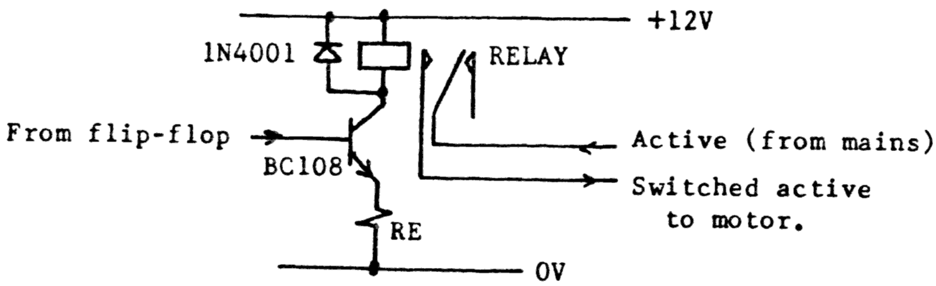
COMPONENT	QTY	UNIT PRICE
Integrated circuits:		
LM1812 Ultrasonic transceiver	1	$10.50
4522 Programmable ÷N 4-bit counter	1	$1.45
4027 Dual J-K Flip-flop	1	$0.75
40085 4-bit Magnitude comparitor	2	$1.61
4520 Dual binary Up counter	1	$1.44
4519 4-bit AND/OR selecter	2	$0.62
4011 Quad 2-input NAND	1	$0.45
4001 Quad 2-input NOR	1	$0.35
555 Universal timer	2	$1.00
Resistors: 3.4K	16	$0.05
5% - 1K, 680K, 1.5M, 6.8K, 22K	1ea	$0.05
1% - 510, 160, 20	1ea	$0.09
Trimpots - 5K, 25K, 1M, 10K, 1K	1ea	$0.30
Capacitors:		
100pF, 100nF, 20nF, 220nF, 1nF, 560pF, 10nF(x2) 1.5nF	1ea	$0.12
250uF	1	$0.30
Misc.:		
2N4356 PNP transistor	1	$0.50
Potcores 18mm	1	$3.22
26mm	1	$3.40
8-bit DIP switch	2	$2.35
40KHz Ultrasonic transducers	2	$4.48

TOTAL COST $46.38

ADDITIONAL CIRCUITRY

To make this design fully complete and functional, there are two extra blocks needed.

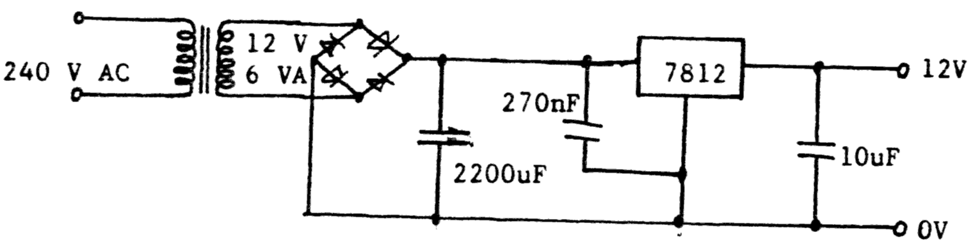
The first is the interface between the controlled motor and the output of the digital section. In this case a relay should be used to switch the motor and as the unit is used to control a variety of motors, the relay should be chosen after the motor specifications are known. In any case, the circuitry used is shown in Fig.7.



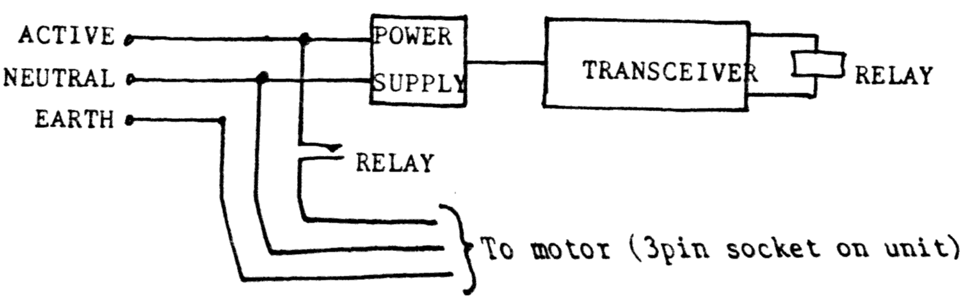
RE is chosen depending on the relay current.

ie RE = 11/I where I = relay current.

The other block needed is the power supply. The requirements on the power supply are not much, a current supply of 0.5A is ample and the voltage should not exceed 18V. A suggested circuit would be :



Given that an 'on board' power supply is used, the physical set-up shown below would be preferrable to allow the user to plug the motor cord into the unit, this abrogates the need for any external wiring changes.



OPERATING AND MAINTENANCE

With the unit completed as suggested in the previous section, the operating instructions are quite simple. All that's required to set up the unit on location is this :

1 - Position the transducers so the sound wave is reflected directly back. Be carefull about unwanted reflections from the side of the container or other obstructions.

2 - Set the required upper and lower levels on the DIP switches using the chart provided.

3 - Plug the unit into a mains socket and switch on.

4 - Plug the motor cord into the socket on the unit.

5 - Check that the levels set are right. If not, make some minor adjustments with the lower order bits on the DIP switches.

If the unit doesn't seem to be working but does trigger with a hand (or piece of card) moved in front of the sensors, it probably means that the transducers are not quite perpendicular above the surface to be measured. This effect is because the reflected pulses are not being received, so some adjustment is needed in the positioning of the sensors.

The maintenance of the unit is also quite simple. All that needs to be checked fairly regularly is that the transducers do not get covered with dust. With the transducers covered with a thin membrane they will work in a dusty environment but a build-up of dust on the membrane will reduce the working distance and eventually stop the unit operating at all. It is recommended that the transducers be wiped carefully fairly regularly, say 2 or 3 weeks depending on how often it is used.

SWITCH POSITION TABLE

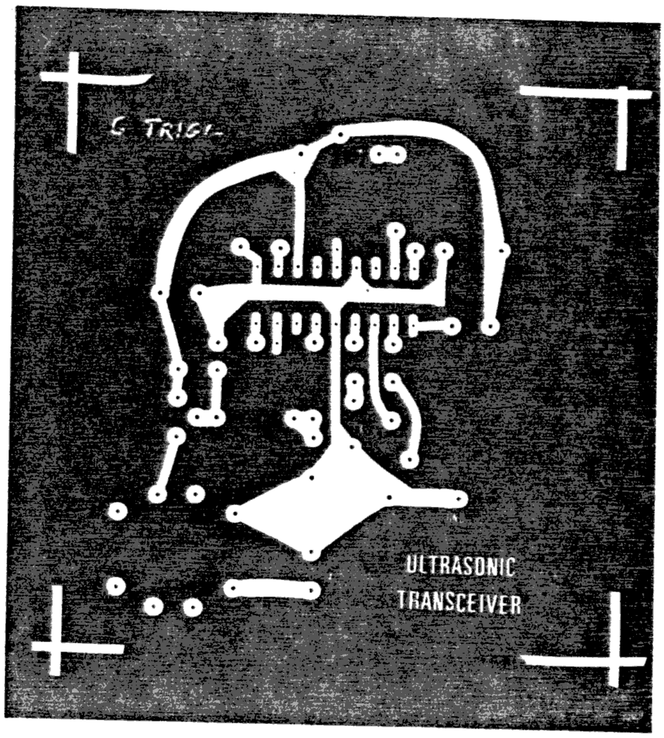
The following table is a guide to the settings on the DIP switches for various distances. They should only be used to give a starting value and will usually need some adjusting when the unit is switched on.

DISTANCE (cm)	SWITCH SETTING
8	00000101
10	00000110
12	00000111
14	00001000
16	00001001
18	00001010
20	00001011
24	00001101
26	00001111
30	00010001
40	00010110
50	00011011
60	00100000
70	00100101
80	00101010
90	00101111
100	00110100
110	00111001
120	00111110
130	01000011
140	01001000
150	01001101
160	01010010
170	01010111
200	01100110

The '1' means the switch is in the ON position and the '0' corresponds to OFF.

P.C.B. LAYOUT

The diagram shown below is the printed circuit board layout for the ultrasonic transceiver section of the design.



REFERENCES

ETI Circuit Techniques Vol.1&2.

IEEE Journal Of Solid State Circuits Vol. SC9 N°6 Dec.'74

'A single chip monolithic sonar system'.

Electronic data books.

DESIGN PROFILE PROJECT Ultrasonic Level Detctor

Student Name GLENN TRIGG

Supervisor Mr. F.Payne

Proposer Glenn Trigg