DEPARTMENT OF PHYSICS

3rd/4th YEAR
UNDERGRADUATE
TEACHING LABORATORY

INSTUMENTATION PROJECT

PLEASE **<u>DO NOT</u>** REMOVE
BENCH NOTES FROM
THE LABORATORY

(OCT 2010)

PROPOSED SCHEME OF WORK
FOR P.C.B. DEVELOPING AND ETCHING EQUIPMENT

EQUIPMENT :- MEGA TRI TANK PA310 & MAPLIN BUBBLE ETCH TANK

LOCATION :- J.A. ROOM 5:06 (FUME CUPBOARD)

USERS :- ELECTRONIC WORKSHOP / INSTRUMENTATION (UNDERGRADUATE COURSE)

PERSON IN CHARGE :- Dr N. LOCKERBIE

SAFETY PROCEDURES

AVOID UNNECESSARY EXPOSURE TO LIGHT EMITTED FROM ULTRA VIOLET SOURCE

PROTECTIVE CLOTHING MUST BE WORN AT ALL TIMES (GOGGLES,GLOVES AND APRONS)

DURING CHEMICAL PREPARATION WHERE POWDERS ARE INVOLVED, DUST MASKS MUST BE WORN

AVOID SKIN AND EYE CONTACT. DO NOT SWALLOW.

IN THE EVENT OF SKIN CONTACT WASH WITH SOAPY WATER

IF SWALLOWED, DRINK LOTS OF WATER INDUCE VOMITING AND SEEK MEDICAL ADVICE

ANY SPILLAGE'S MUST BE CLEANED WITH WATER IMMEDIATELY

ANY LEAKS FROM TANK OR WATER SUPPLY MUST BE REPORTED TO DESIGNATED STAFF IMMEDIATELY

P.C.B. DEVELOPER AND ETCH BASKETS MUST ONLY BE WASHED IN CENTRAL SPRAY WASH UNIT OF TANK

ONLY A MAXIMUM OF FOUR PERSONS TO USE TANK AT ANY ONE TIME

EQUIPMENT MUST NOT BE USED UNLESS DESIGNATED MEMBER OF STAFF PRESENT (INSTRUMENTATION COURSE)

EQUIPMENT MUST NOT BE TAMPERED WITH

WHEN DRILLING P.C.B'S SAFETY GOGGLES / GLASSES MUST BE WORN

EQUIPMENT MUST NOT BE MOVED UNLESS DESIGNATED MEMBER OF STAFF PRESENT

ONLY DESIGNATED CHEMICALS TO BE USED

P.C.B. PROCEDURE AND HEALTH PRECAUTIONS MUST BE READ BY EVERYONE WHO WILL USE EQUIPMENT

P.C.B. PROCEDURE

P.C.B'S SHOULD BE INITIALLY EXPOSED IN U.V. UNIT FOR THREE AND ONE HALF MINUTES

PC.B'S SHOULD BE PLACED IN THE DEVELOPER FOR APPROX ONE MINUTE. TIME WILL VARY DEPENDING ON AGE OF THE CHEMICAL

AFTER SPRAY WASHING. BOARD SHOULD BE PLACED IN ETCHANT. TIME WILL ALSO VARY DEPENDING ON HOW EXHAUSTED ETCHANT IS. TYPICAL TIMES VARY FROM 5 MINUTES TO 30

AVOID CROSS CONTAMINATION OF CHEMICALS.
ALTHOUGH NOT DANGEROUS CROSS CONTAMINATION WILL REDUCE EFFICIENCY OF PROCEDURE AND GREATLY INCREASE THE TIME TO COMPLETE PROCEDURE.

SPRAY WASH BOARD AFTER ETCH

PLACE BOARD BACK IN U.V. SOURCE FOR SET TIME

PLACE BOARD IN DEVELOPER UNTIL ALL PHOTO RESIST HAS BEEN REMOVED

SPRAY WASH BOARD

BOARD CAN NOW BE DRILLED. SAFETY GOGGLES / GLASSES MUST BE WORN

DESIGNATED STAFF

DR N. LOCKERBIE
COURSE DEMONSTRATORS
LAB TECHNICIAN

DESIGNATED CHEMICALS

DEVELOPER :- SENO 4006V05
ETCHANT :- SENO FINE ETCH CRYSTALS

INSTRUMENTATION PROJECT

1. Introduction

In this project you are asked to make an electronic instrument from a basic design. The work should give you experience of the various techniques used in circuit board manufacture, soldering, trouble-shooting and calibration. It should teach you how to read complex circuit diagrams and how to test complex circuits.

Project work implies a certain open-endedness of the work with variable end results. It implies a certain freedom of approach, giving individuals the opportunity to work in ways they regard as best suited to them and to the overall aims of the project. We are therefore looking for a professional approach to the work, as shown in individual initiative, competence and speed:

> *Initiative* means self-help with regard to getting information or advice. Remember that you are in charge of the project and are responsible for its successful completion.
>
> *Competence* means purposeful work, without over-elaborating or skimping. Purposeful testing means dividing the task into testable sub-sections that need to be seen to work individually. If something does not work, then analyse the problem by divising simpler tests designed to isolate the problem. All this demands a good understanding of how the instrument should work.
>
> *Speed* is always important in a professional working environment. This means you manage your time, divide out the work and ensure good progress through a thorough familiarity with all aspects of the project.

At the end of the project you should have gained some understanding of the techniques of electronics construction and testing. You should also understand the workings and limitation of the design you have constucted and be in a position to suggest design improvements. Finally, you should have assessed some *fundamental* limitations of such techniques in general, for the purpose for which this instrument has been designed and have some ideas about other applications areas in which this approach might be useful.

2. The Instrument - Ultrasonic Rangefinder

The instrument you are asked to make is an ultrasonic rangefinder. With this instrument, the distance between instrument and target object is determined by measuring the round-trip time from transmitted ultrasonic pulse to received echo from the object (as in radar).

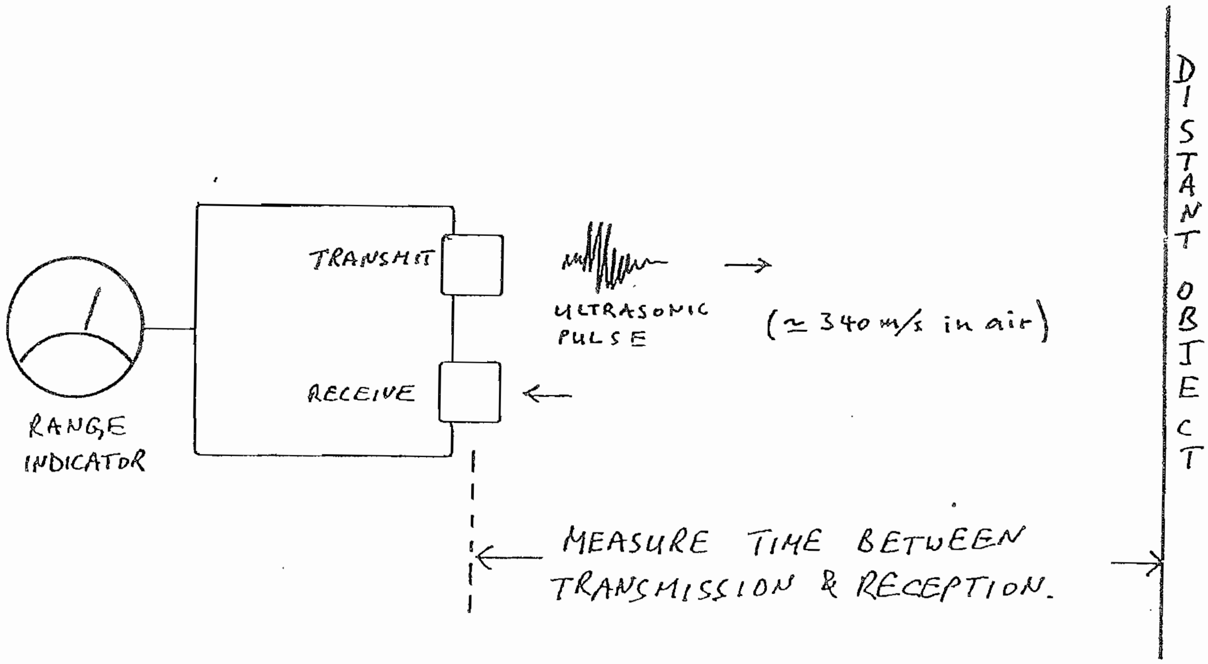


Figure 1: *Principle of operation of the ultrasonic rangefinder.*

The instrument should have a maximum range of 3m or more when used with a large, plane reflector, such as a wall. After calibration, the accuracy should be 5% or better.

3. Design Outline

A block schematic diagram of the instrument is shown in Figure 2.

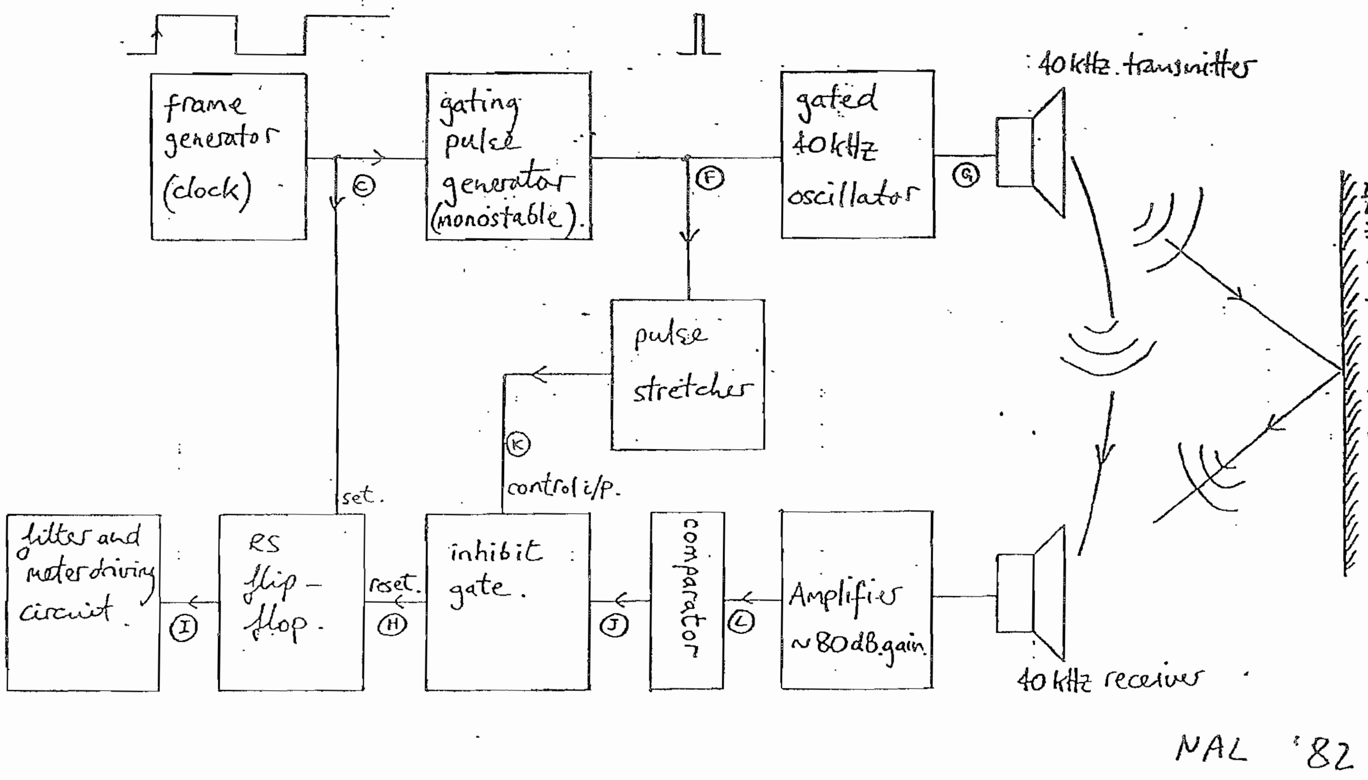


Figure 2: *Block schematic diagram of the rangefinder*

The instrument appears complex at first sight, but remember that all complex circuits can be broken down into sub-units. You can read figure 2 as follows:-

1. You need to generate ultrasound. This requires an ultrasonic transducer (transmitter), driven by an oscillator.

2. You don't want a continuous note being emitted, you want a pulse (a tone burst). For this you need to "gate" the oscillator on and off. So, the oscillator needs to be a gated oscillator. The gating pulse generator produces a control signal to gate the oscillator on for a suitable length of time.

3. You want the instrument to emit tone bursts at regular intervals, going through the measurement process repeatedly. In this way the meter reading is continually updated as the range changes. The frame generator (clock) initiates a new measurement each time its output square wave changes from low to high.

4. On the detector side, the ultrasonic receiver picks up a weak signal, which needs to be amplified. The amplified signal is then passed through a comparator circuit which does two things:
   (a) It prevents low amplitude signals and noise from being passed on to the timing circuit. Only signals of "significant" amplitude are passed on.
   (b) It produces standard amplitude logic signals at the output from variable amplitude input signals. Further signal processing can therefore be done using digital techniques.

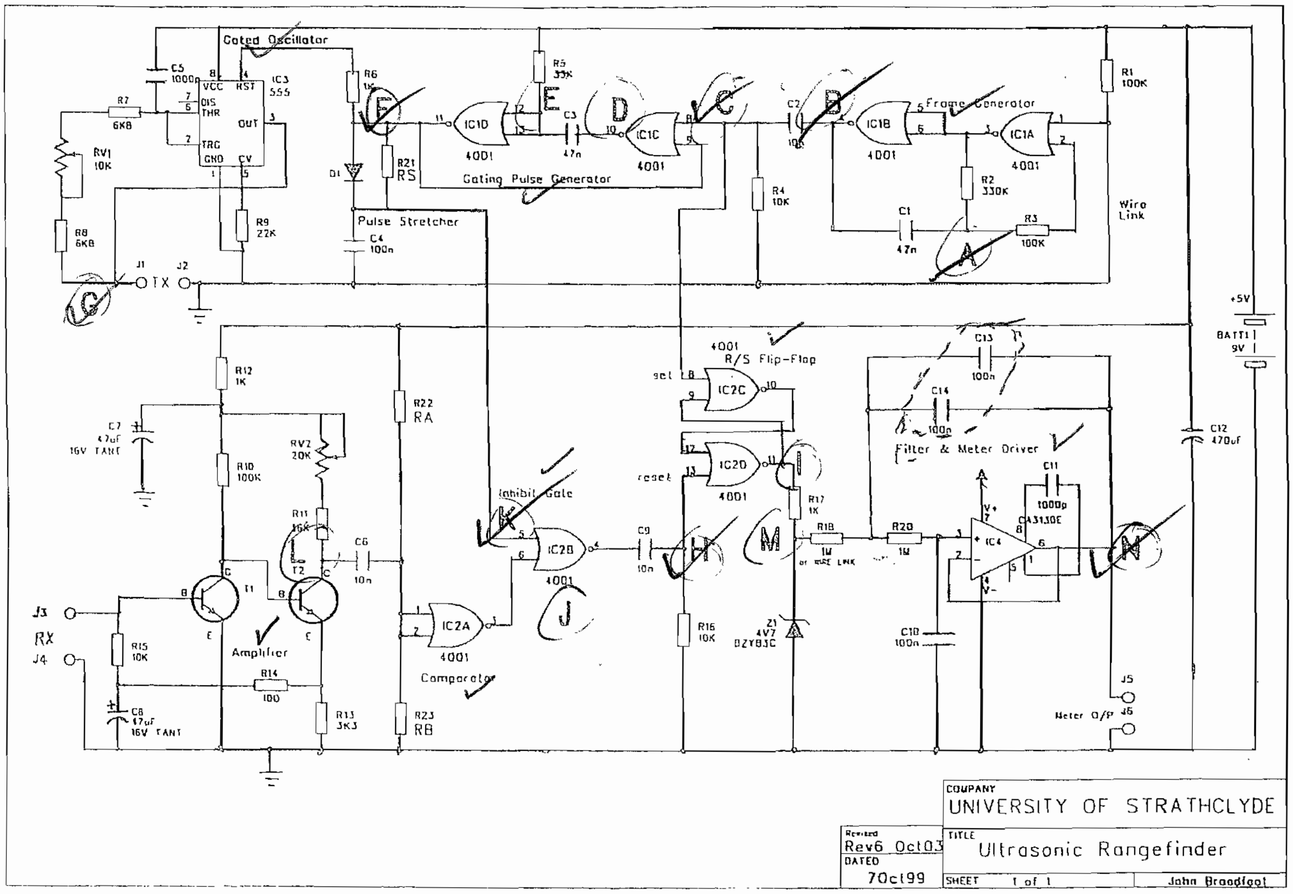
5. The basic timing circuit is the R-S (reset-set) flip-flop. The output is "set" by the frame generator, signifying the start of the tone burst. It is "reset" by the first signal that manages to pass the comparator and inhibit gate (of which later). The duration of the set interval is therefore the duration of the time of flight of the ultrasonic tone burst, and therefore proportional to the range.

6. The filter and metering circuit generates an output proportional to the flip-flop set-time, and therefore range, by averaging the output of the R-S flip-flop. If the R-S flip-flop spends most of its time in the "set" condition, then the time-averaged output is large, as is the range. If the R-S flip-flop is reset almost immediately after set, then the time-averaged output is low, as is the range.

7. The design cannot yet work properly, because the direct signal from transmitter to receiver would reset the flip-flop almost immediately after being set, irrespective of range! This direct signal is stopped by the inhibit gate. The gate is shut by the pulse controlling the transmitter oscillator. This inhibit period is too short in practise because the receiver transducer is resonant, producing some output after the input has gone to zero. For this reason the gating pulse is passed through a pulse-stretcher, to prolong the inhibit period sufficiently to eliminate the effects from direct signal.

4.The Circuit

Figure 3 is the translation of the block schematic design (figure 20 into actual circuit Components. A careful study of this should now be rewarding. I have identified the various boxes of figure 2



⊙ 9 volt battery or stabilized voltage supply *

FIGURE 3 : Circuit diagram of the rangefinder

1. The gated oscillator is IC3 - the ubiquitous 555 timer. The ultrasonic transmitter (TX) is driven by pin 3 (output). The oscillation frequency is determined by C5*(R7, R8, RV1). You can adjust the frequency of the tone with RV1 - this is necessary because the transmitter and (even more) the receiver transducers are resonant, with frequencies that vary somewhat from device to device. Pin 4 is the gate input:- The circuit will oscillate only if a logic high is applied.

2. The gating pulse generator consists of two NOR gates from IC1: 1C and 1D. They are connected together via C3 and R5, with feedback to pin 9, to form a monostable circuit. When triggered at 8, the output 11 goes high for a time determined by C3*R5.

3. The frame generator consists of two NOR gates from IC1: 1A and 1B. They are connected together to form a multivibrator circuit, producing a square wave at pin 4, of frequency determined by $(C1*R2)^{-1}$.

4. The amplifier circuit uses two low noise transistor in an emitter feed-back arrangement. The amplified signal is AC-coupled, via C6, to the comparator circuit, consisting of NOR gate 2A of IC2, together with resistors RA and RB. The comparator will switch when its input voltage at pins 1 and 2, exceeds the logic threshold voltage. This logic threshold voltage, in CMOS logic is approximately equal to one half the supply voltage, *ie* 4½ volts when using a 9V battery. RA and RB are selected to give a steady bias to pins 1 and 2, some hundreds of millivolts below the logic threshold. The signal from the receiver is then superimposed on this steady level. Any excursions that exceed the logic threshold will produce an output change at pin 3. Because of component variations, RA and RB may need to be adjusted for optimum circuit performance.

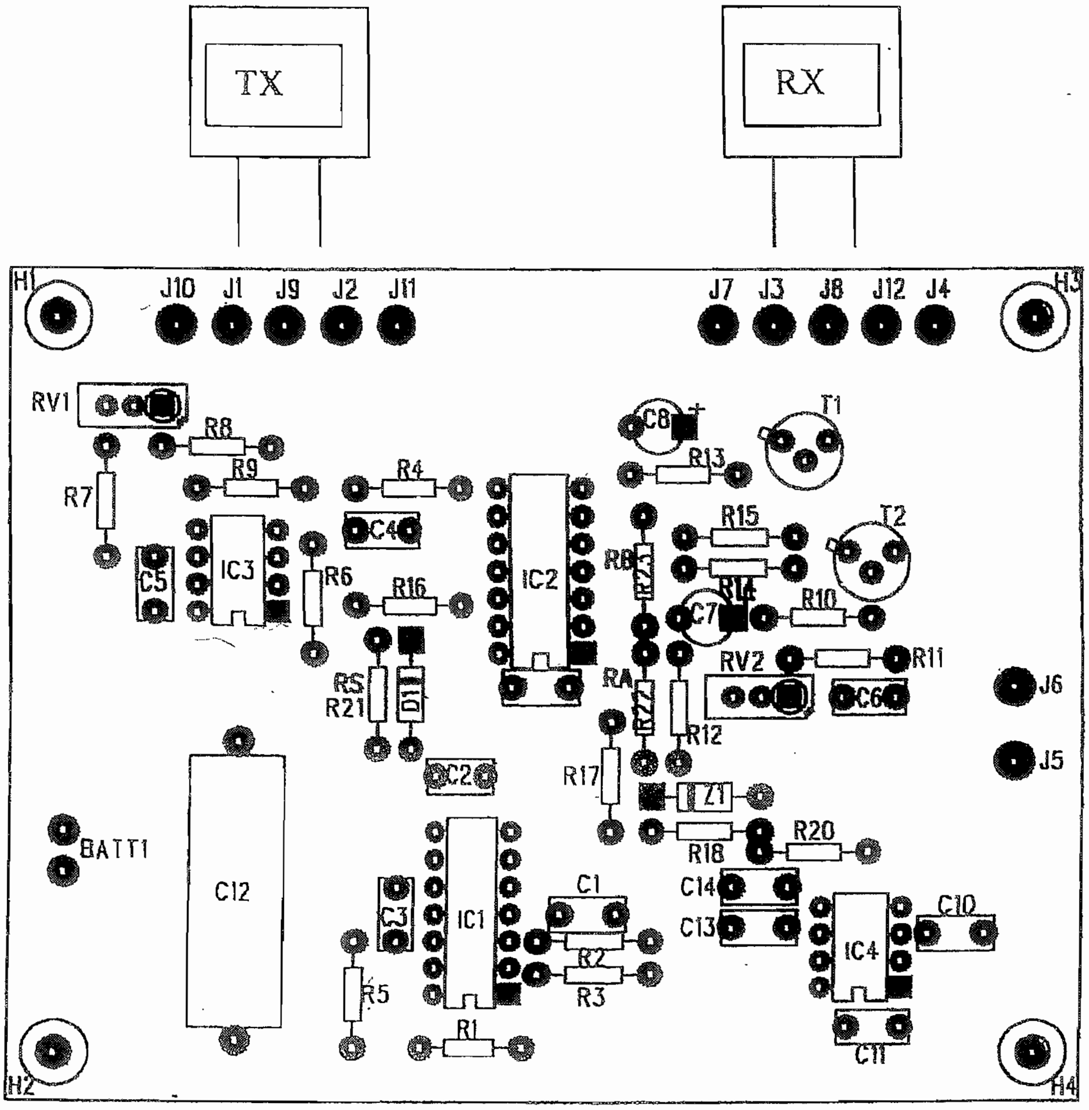
5. The timing circuit is the R-S flip-flop, constructed from two cross-coupled NOR gates, 2C, 2D of IC2. The output at pin 11 is set by a signal at pin 8 from the frame generator, and reset by a signal at pin 13 from the pulse echo.

6. The filter and meter drive circuit uses an operational amplifier type CA3130, IC4, operated as a voltage follower. RC filtering is achieved by means of R18 and C10. The zener diode ensures that the voltage presented to R18 is constant, 6.8V, irrespective of battery condition to maintain calibration. The op-amp output is passed through the meter via R19 and RV2. RV2 can be adjusted to give the required calibration.

7. The inhibit gate is NOR gate 2a of IC2. Signals from the comparator will be passed (and inverted) only if the logic level at pin 5 is low. While pin 5 is high, the output at 4 will be low irrespective of the signal on pin 6. The inhibit signal is generated from the oscillator gating pulse (pin 11 of IC1), stretched by means of RS and C4. The diode D1 by-passes RS at the beginning of the inhibit period, causing a rapid assertion of the inhibit state. The diode becomes reverse-biassed once the gating pulse goes low again, thus ensuring that C4 discharges through RS, to give an exponentional decay to the trailing edge of the inhibit pulse - hence a stretching. Component variations may require RS to be adjusted for optimum performance.

INSTRUMENTATION PROJECT

PRINTED CIRCUIT BOAD LAYOUT



NOTES

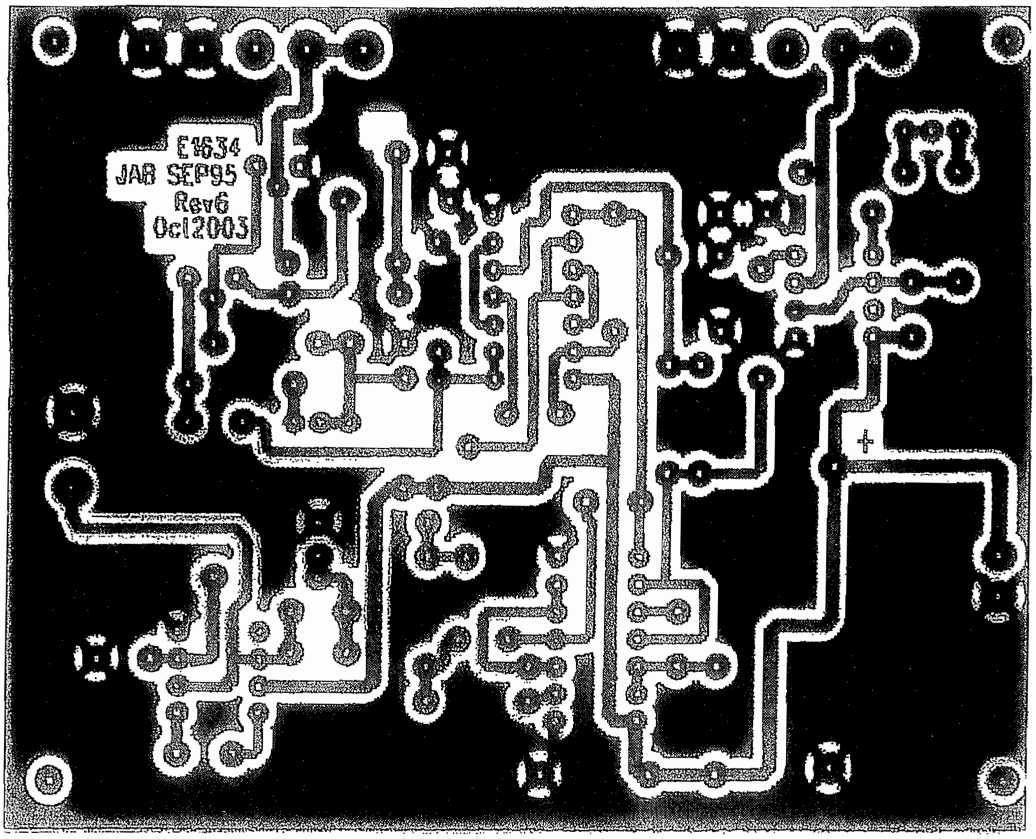
Ra ON THE SCHEMATIC IS HERE LABELLED R22

Rb ON THE SCHEMATIC IS HERE LABELLED R23

Rs ON THE SCHEMATIC IS HERE LABELLED R21

FOIL PATTERN

Meter



Battery

TRACK VIEW OF PCB MASK

6. Construction Notes

You are given an acetate transparency with the track design, correctly scaled to produce a printed circuit board (PCB) by contact exposure with a photoresist coated fibre - glass / copper board. The production steps are as follows :-

1. Put the acetate sheet in contact (in the correct orientation) with the photoresist coated copper board and expose to UV for $3^1/_2$ minutes.

2. Place the UV exposed board into the developer bath and check after 30 seconds. (Time will vary depending on the age of the chemical)
   If the board has been developed properly then a clear , sharp image of the tracks should be visible.

3. Spray wash the board and dry it thoroughly.

4. Place the board into the etch bath and etch for 5-10 minutes as necessary. Be careful with the etchant it is corrosive. Always wear eye protection and avoid contact with skin or clothing. (Please refer to the safety procedures at the start of this script).

5. Spray wash the board.

6. Place the board back in the UV source for set time and then develop board as before until all the photoresist has been removed

7. Spray wash the board. The board is now ready to be drilled.

8. Two drill bits are used.

   1mm drill bit for the terminal pins (i.e. battery, meter and U/S transducer connections)
   0.8mm drill bit for the rest of the components.

The board is now ready for populating. It is strongly recommended that the circuit be built in testable sections :

(i) Gated oscillator
(ii) Gating pulse generator and frame generator
(iii) Amplifier
(iv) Comparator
(v) Pulse stretcher and inhibit gate
(vi) R-S flip -flop
(vii) The rest

Remember that nothing works until you have seen it working.

Soldering technique is very important. The soldering iron should be regarded as a source of heat, rather than a source of solder. Place the solder - wetted tip onto the solder pad and wire to be joined. Touch the pad and wire with solder wire. When hot enough the solder wire will melt, bringing with it the all important flux for cleaning up oxide and other deposits. The new solder and flux should flow freely onto the joint not onto the iron. If you do not apply sufficient heat to the parts to be soldered, or if you allow the flux to be used by the soldering iron rather than the parts to be joined, then a dry joint may result. This looks OK, but has a built- in insulating barrier - trouble for sure !. Do not over solder either. You can easily bridge adjacent pads this way.

N.B. The photoresist on the tracks acts as a fluxing agent when soldering.
However, enough heat is required to ensure the solder bonds to the copper underneath.

Other points to remember:-

(i) Use a solder pump or rework station for de-soldering.
(ii) Use IC-sockets, to ease trouble-shooting.
(iii) Handle C-MOS circuits with care. Avoid touching the pins until the circuit is installed on the PC card. Static electricity can destroy C-MOS circuits.
(iv) Remember that tantalum and electrolytic capacitors are poled - they have to be connected in the correct orientation.

7. Trouble-shooting and Testing

Test in small sections as you build up. The oscilloscope is your main test instrument. Initially, just a check of the waveforms at the various marked points (the waveforms of Appendix 2 correspond to the points marked in figures 2 and 3) is enough. However, as more sections are completed, you will need to be able to observe the time relationship between two or three waveforms. This can be achieved by using one waveform (*eg* B) as a trigger in the external trigger input of the oscilloscope. When set up in this way, the oscilloscope sweep starts at the same instant as a measurement cycle and the delays between the various other waveforms can then be observed directly in the two channels of the oscilloscope. It is then easy to observe, for example, which signals cause the comparator to react; at which point in time the inhibit gate is opened; *etc*. For the instrument as a whole to work, such timings and threshold settings are important.

Finally, you will need to calibrate the instrument as in figure 6.

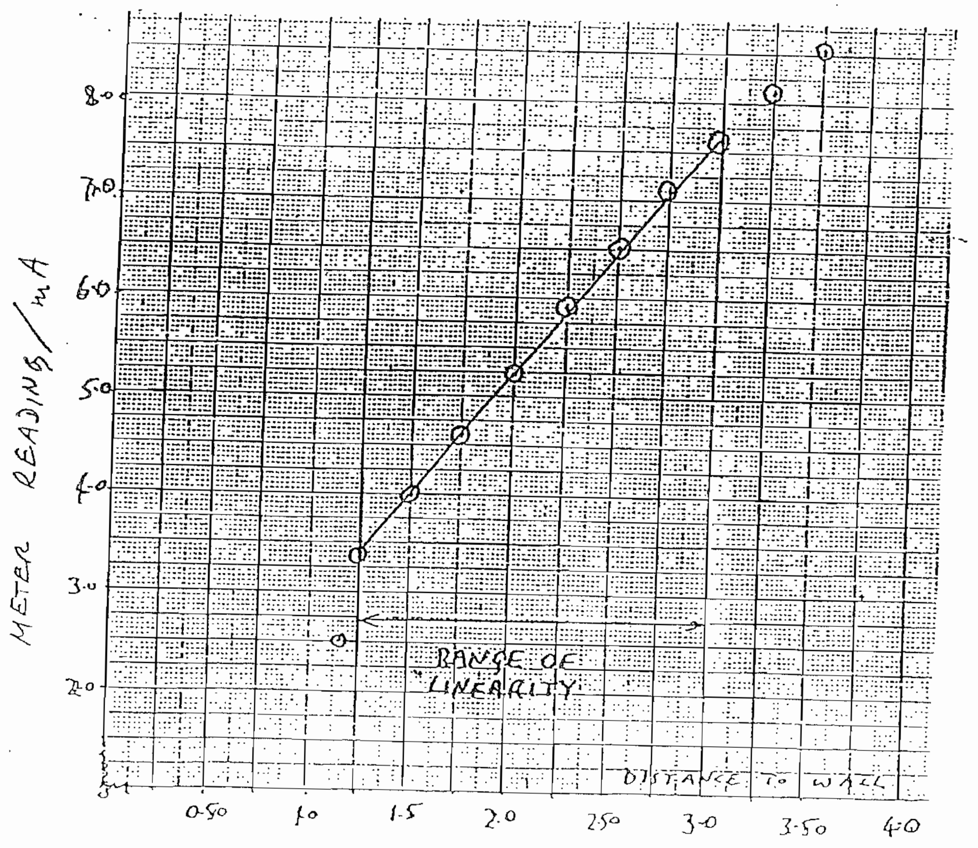


Figure 6: *Sample calibration curve*

LIST OF COMPONENTS

RESISTORS

R1	100K
R2	330K
R3	100K
R4	10K
R5	33K
R6	1K
R7	6K8
R8	6K8
R9	22K
R10	100K
R11	36K
R12	1K
R13	3K3
R14	100R
R15	10K
R16	10K
R17	1K
R18	1M (or wire link)
R20	IM
RV1	10K ¾ inch 20 turn trimmer
RV2	20K ¾ inch 20 turn trimmer

Notation
100R = 100ohm
6K8 = 6.8K ohm
1M = 1megaohm

Ra 47k) these values
Rb 33k) need to be adjusted
Rc 56k) for optimum performance

CAPACITORS

C1	47nf
C2	10nf
C3	47nf
C4	0.1µf
C5	1000pf
C6	10nf
C7	47µf (16v Tantalum bead)
C8	47µf (16v Tantalum bead)
C9	10nf
C10	0.1µf
C11	1000pf
C12	470µf (25v Axial electrolytic)
C13	100nf
C14	100nf

Misc

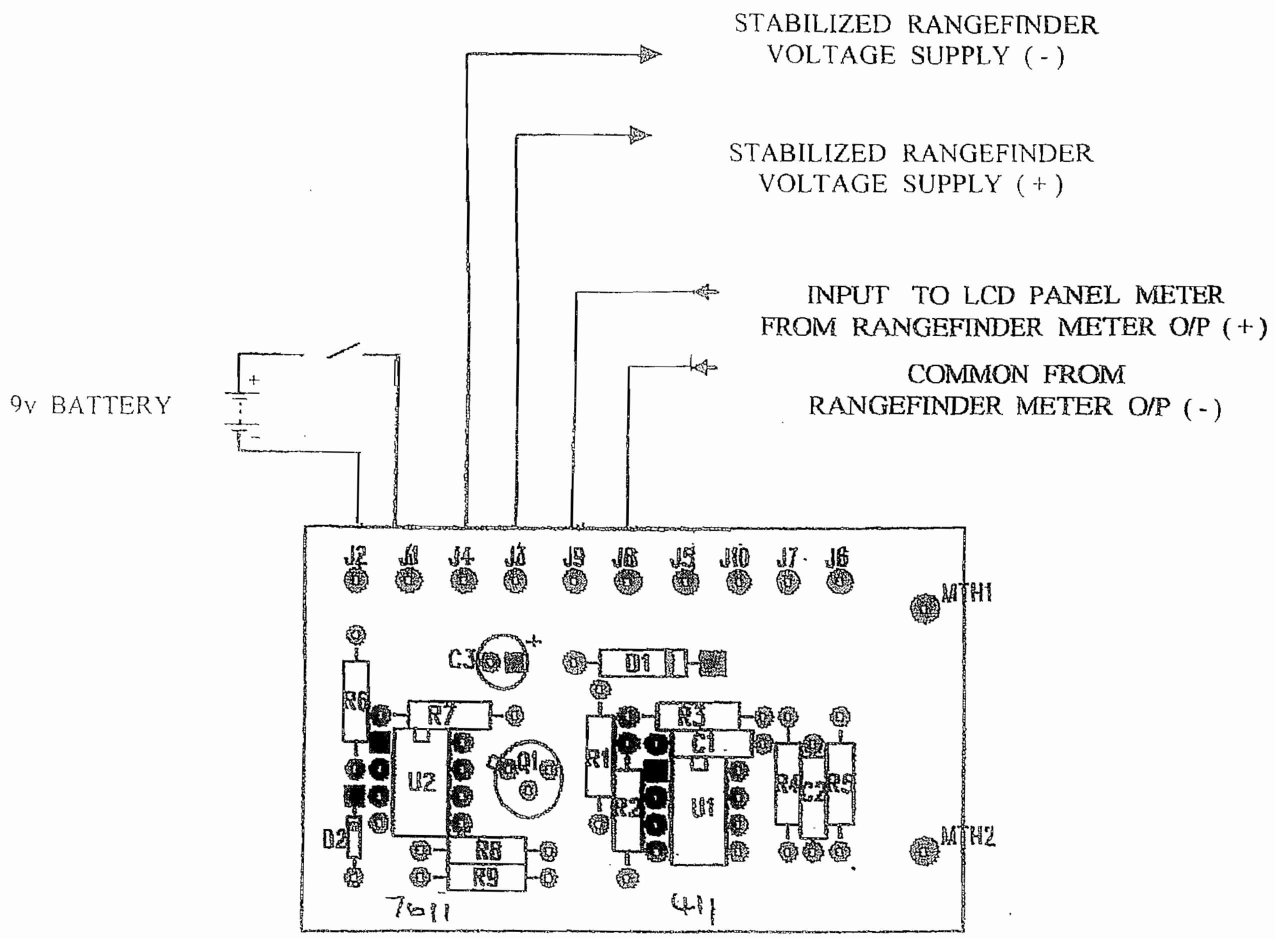
T1	BC 109		
T2	BC 109		
IC1	4001	quad NOR gate, 14 pin DIP)	
IC2	4001	quad NOR gate, 14 pin DIP)	USE
IC3	555	Timer 8 pin DIP)	SOCKETS
IC4	CA 3130	op-amp)	

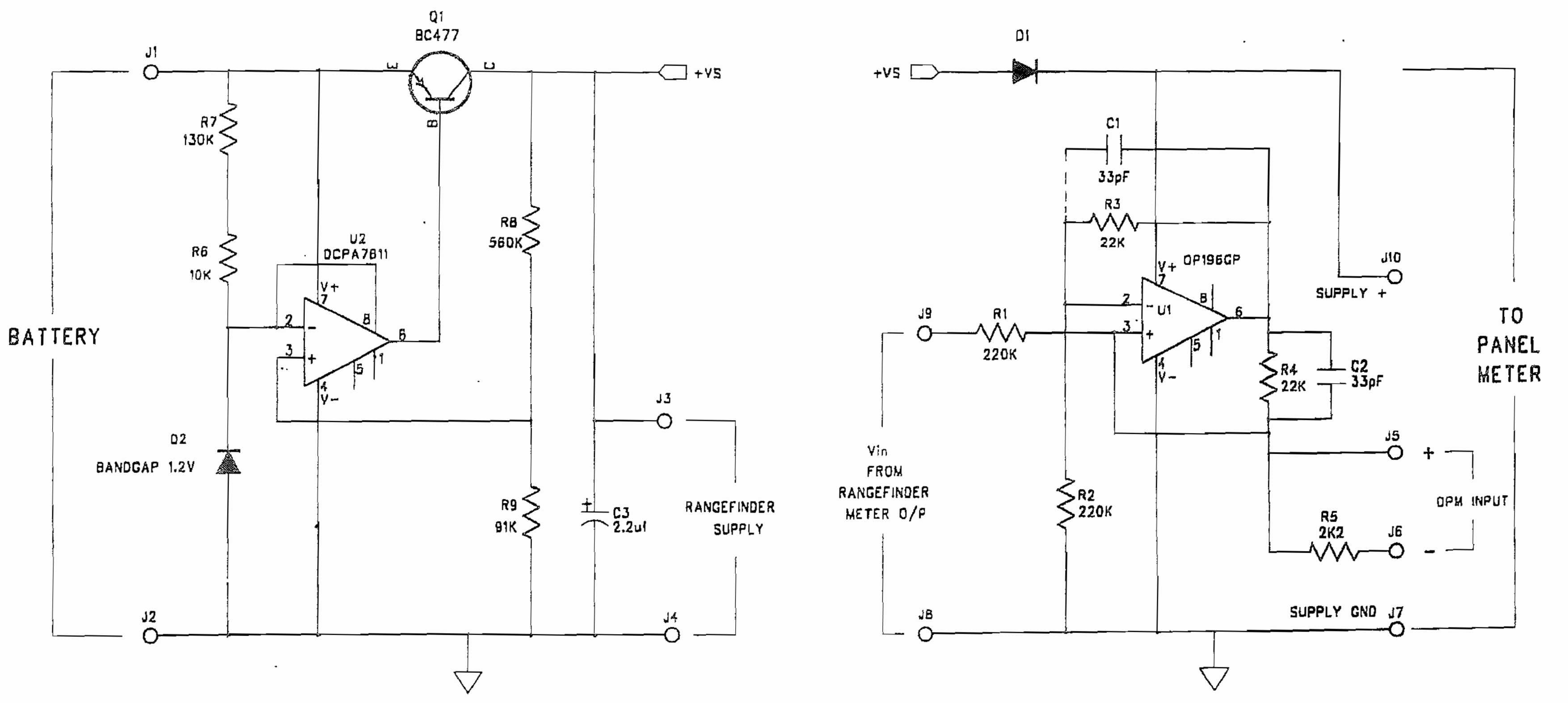
D1	1N 4148	signal diode
ZD1	BZY88C	6.8 volt zener diode
Tx	ultrasonic transmitter	(RS type 307-351)
Rx	ultrasonic transmitter	(RS type 307-367)

(INSTPROJ) REI:JC:5G

INTERFACE P.C.B.

STABILIZED POWER SUPPLY
& INTERFACE TO L.C.D. PANEL METER





	UNIVERSITY OF STRATHCLYDE
JOB TITLE	ULTRASONIC RANGEFINDER DPM & REGULATOR CIRCUIT
DATE	SHEET 1 OF 1

APPENDIX 1

Appendix 1 — IC - pinouts

TIMER NE/SE555/SE555C

DESCRIPTION

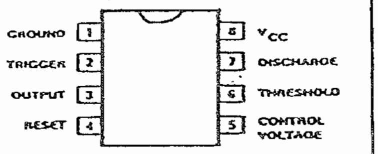
The 555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200mA.

FEATURES

- Turn off time less than $2\mu s$
- Maximum operating frequency greater than 500kHz
- Timing from microseconds to hours
- Operates in both astable and monostable modes
- High output current
- Adjustable duty cycle

PIN CONFIGURATIONS

N, FE PACKAGE



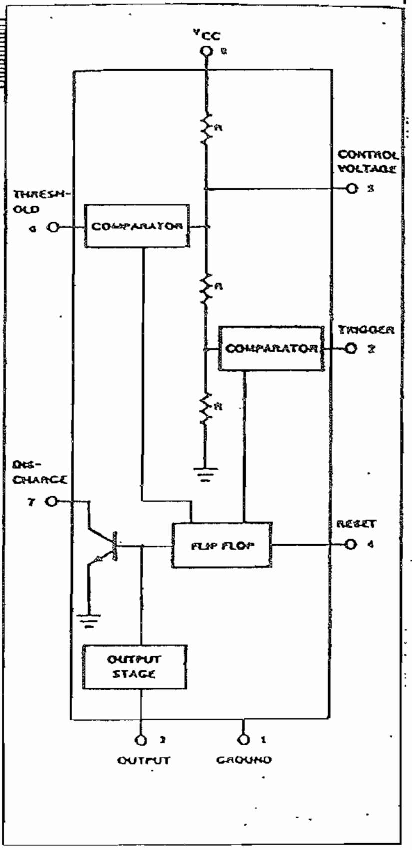
ORDER PART NO.
NE/SE555N,FE
SE555CN,CFE

- TTL compatible
- Temperature stability of 0.005% per °C

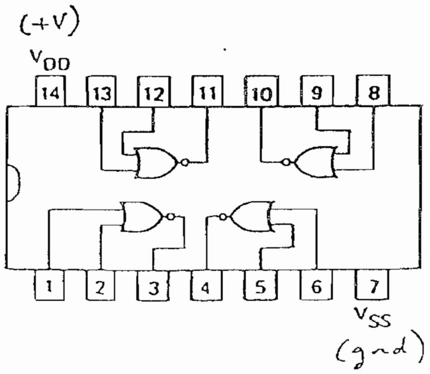
APPLICATIONS

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Missing pulse detector

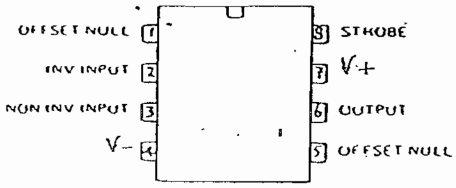
BLOCK DIAGRAM



4001B
LOGIC AND CONNECTION DIAGRAM
DIP (TOP VIEW)



M.O.S./F.E.T. — 3130E



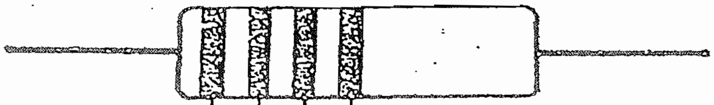
App 2

330 10

Component Colour Codes

E 1828

RESISTORS



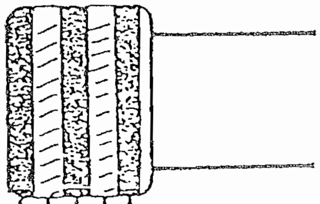
1st. COLOUR BAND	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

2nd. COLOUR BAND	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

	3rd. COLOUR BAND
Silver	Divide by 100
Gold	Divide by 10
Black	Multiply by 1
Brown	" " 10
Red	" " 100
Orange	" " 1,000
Yellow	" " 10,000
Green	" " 100,000
Blue	" " 1,000,000

4th. COLOUR BAND (Tolerance)
Red ± 2%
Gold ± 5%
Silver ± 10%
No Colour Band ± 20%

POLYESTER CAPACITORS



1st. COLOUR BAND	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

2nd. COLOUR BAND	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

3rd. COLOUR BAND	
Orange	x 0.001µF
Yellow	x 0.01µF
Green	x 0.1µF

4th. COLOUR BAND (Tolerance)	
White	±10%
Black	±20%

5th COLOUR BAND (Working Voltage)	
Red	250V d.c.
Yellow	400V d.c.

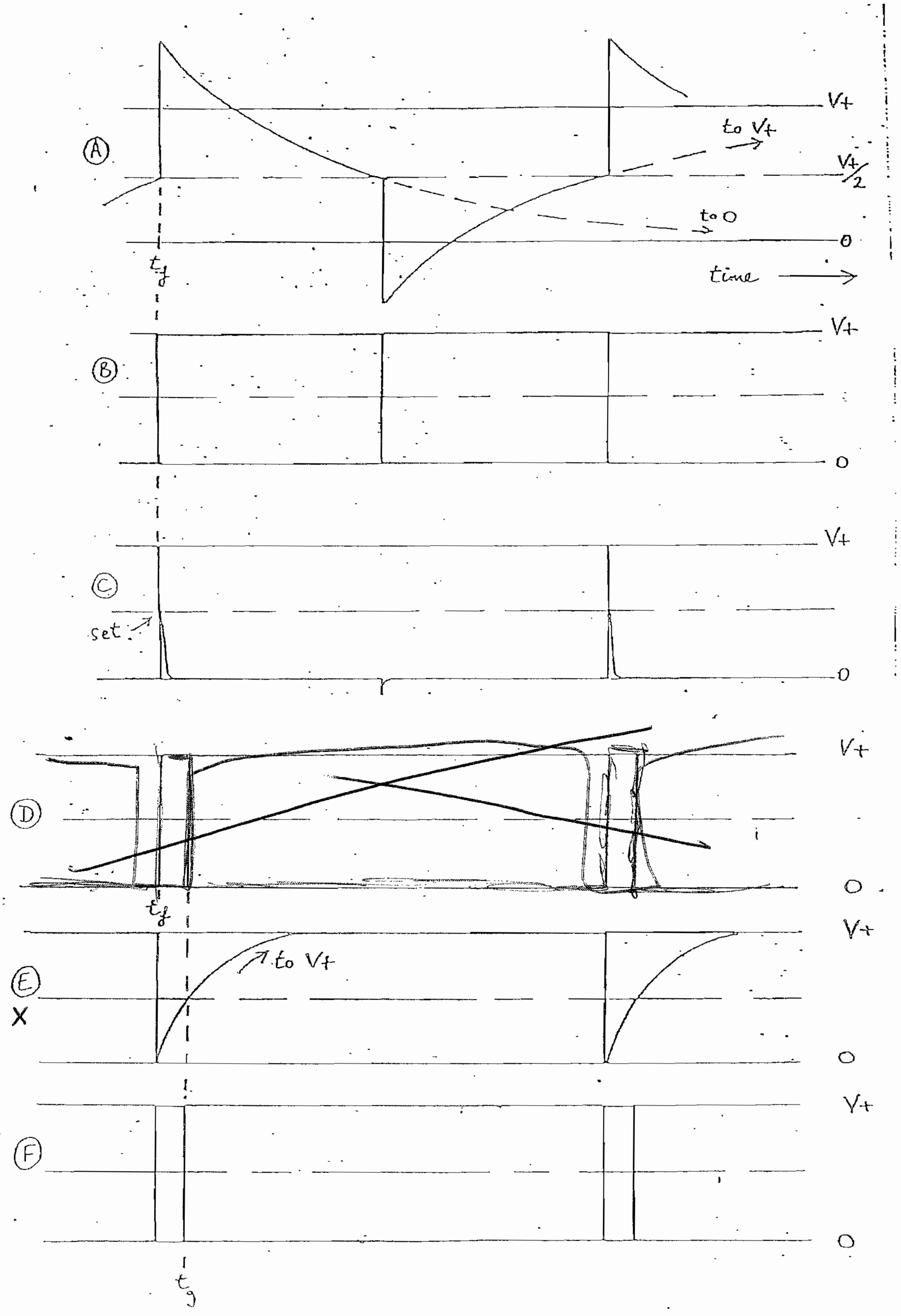
STANDARD DECADE VALUES

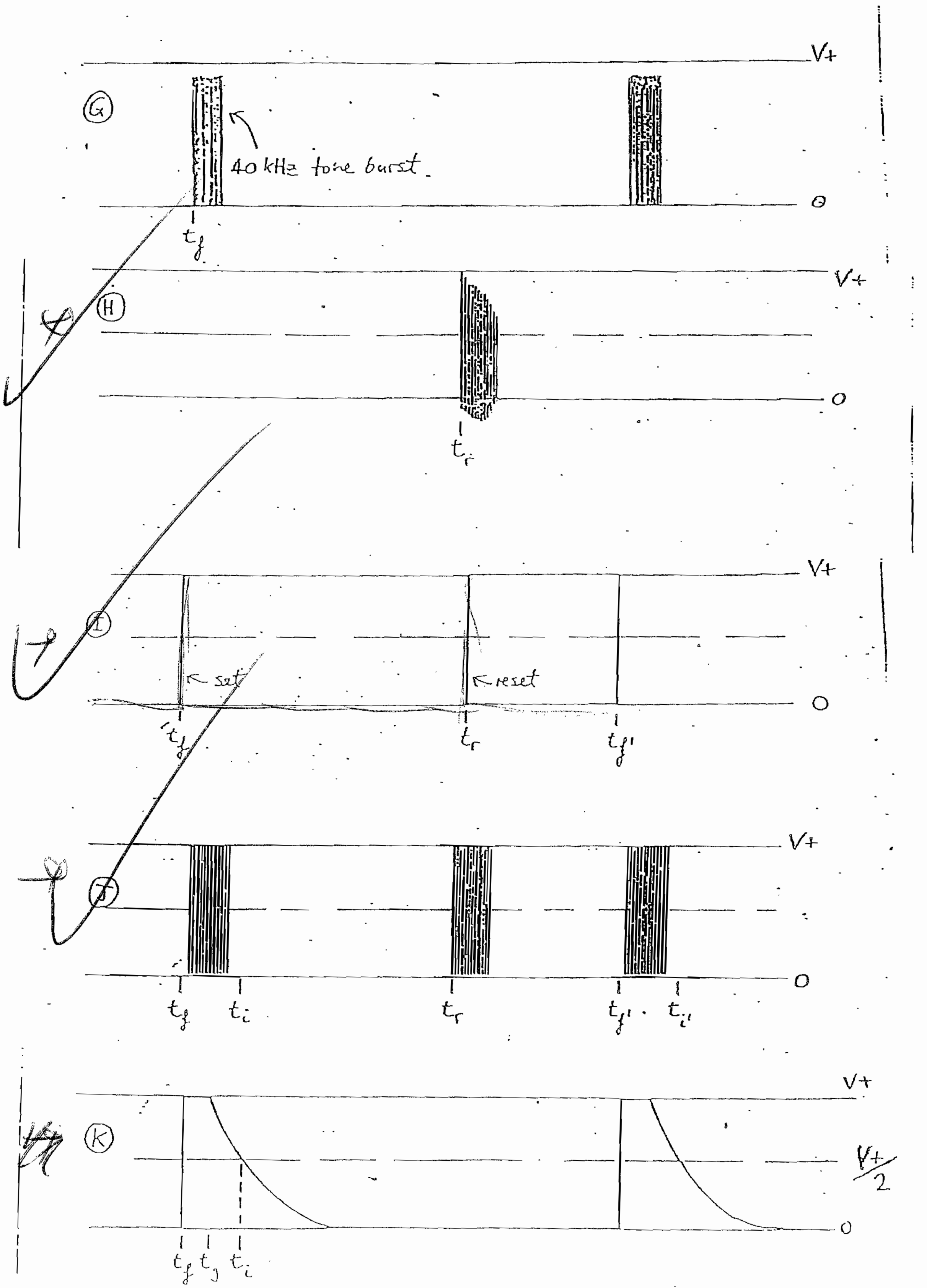
E24	10	11	12	13	15	16	18	20	22	24	27	30	33	36	39	43	47	51	56	62	68	75	82	91
E12	10		12		15		18		22		27		33		39		47		56		68		82	
E6	10				15				22				33				47				68			

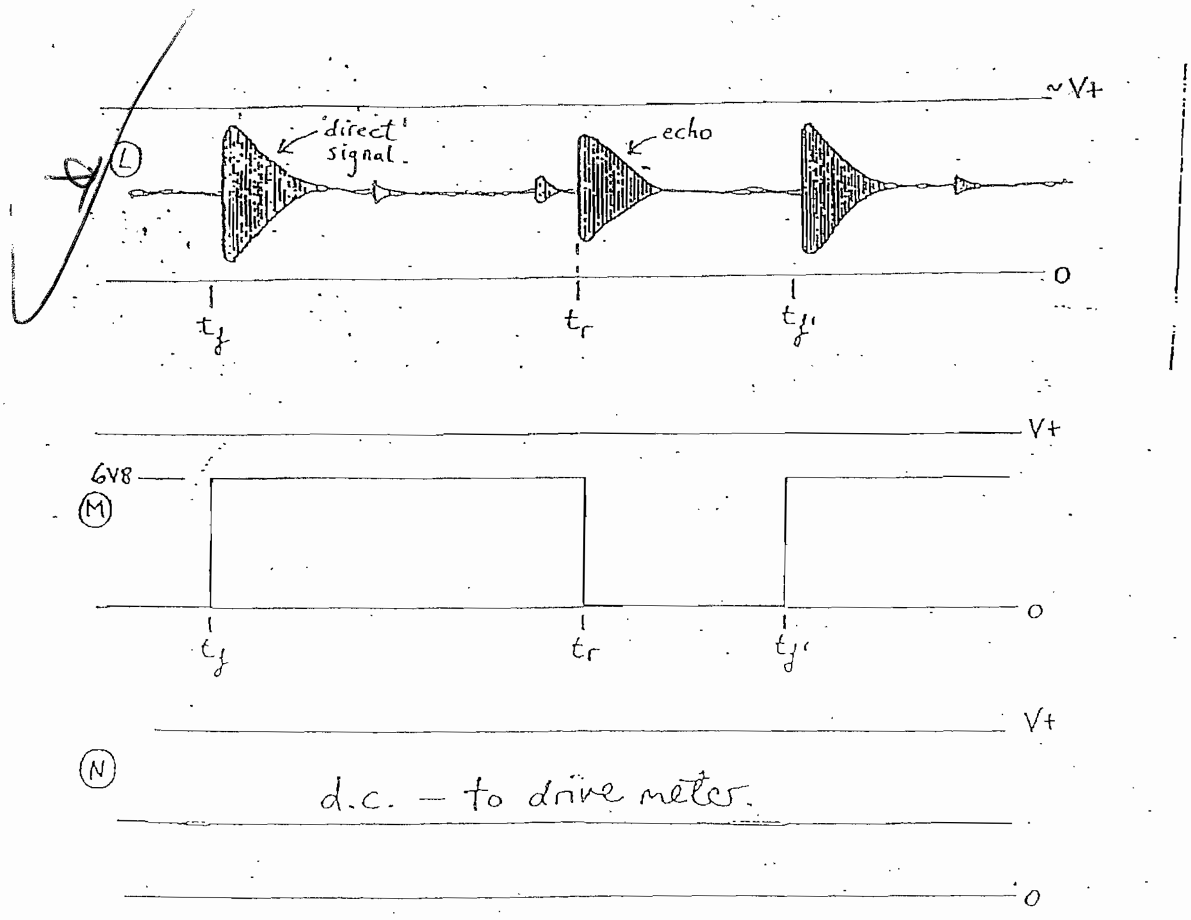
APPENDIX 2

Appendix 2

Signal waveforms at marked test points




V+
G
40 kHz tone burst
0
t_f
V+
H
0
t_r
V+
I
set
reset
0
t_f
t_r
$t_{f'}$
V+
J
0
t_f
t_i
t_r
$t_{f'}$
$t_{i'}$
V+
K
V+/2
0
t_f
t_j
t_i


~V+
'direct' signal
echo
L
0
t_f
t_r
t_f'
V+
6V8
M
0
t_f
t_r
t_f'
V+
N
d.c. – to drive meter.
0