Underground Water Prospecting In Rural Settings

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Abstract
This paper presentsthe design of a portable water table detector. The device can be used to identify where the water table is likely to be found. The heart of the design is on the microcontroller. The ground probes require high voltage and this is generated from a 12 volt battery using a 555 timer arranged as an a-stable multi-vibrator. The use of a battery is to make the device usable even at remote places where electrical power is not available. A suggested code in assemble language for the microcontroller is given as guide. However a high level language can also be implemented, to achieve the same results. The use of the microcontroller (µprocessor) makes it feasible to produce a device that is cost effective for both urban and rural dwellers. The main activity of this design is centred on the development of the code (software program), design of a special power supply and the interfacing external hardware for the detector.

Key Words: Water table detector, electrode interface, PIC microcontroller, Geological strata, resistivity measurement, Analogue to Digital conversion.

1. Introduction

There are various types of water detectors available in the market, but most of these have been designed for countries thatare very developed, hence they tend to be costly and more sophisticated for an ordinary user. This design results in a product that is cost effective in that it uses an inbuilt power supply based on the battery and virtually no moving parts that may require constant maintenance. The system constitutes a software program, control circuits and probe electrodes, as well as the power supply that is incorporated into the system. The device should be able to measure the depth from ground surface to the underground water, and should be easy to operate.The main focus of this paper is to generate motivation and interest in the design and production of devices that are simple to use and suitable for developing technologies.

2. System Overview

Figs 1 and fig 2 shows the setup of the water table detector. The system incorporates four electrodes, two of which are used to pass current through the ground and the other two are used to measure voltage across the specimen ground. Also there is need for signal conditioning to enable proper electrode interface to the microcontroller. Fig 1 illustrates the concept while fig 2 shows how the detector can be used.

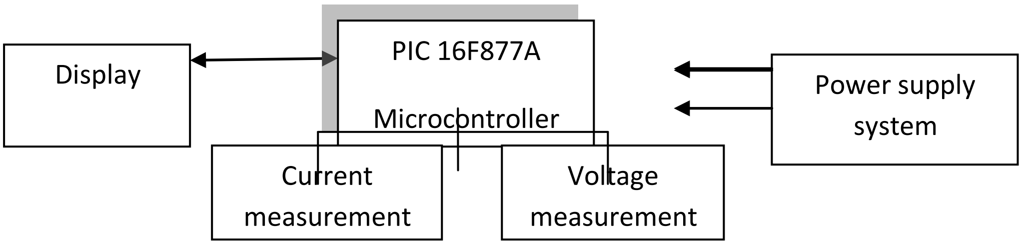

Fig.1. Underground water table detector block diagram

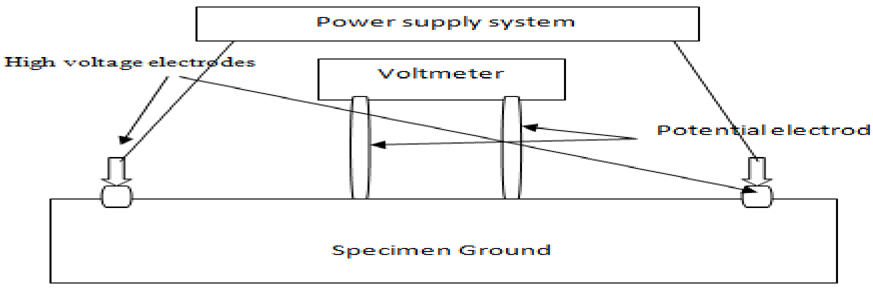

Fig.2. Deployment and usage of the Water table detector

To measure resistivity of subsurface formation, four electrodes are required. A current [I] is introduced between one pair of electrodes called current electrodes. The current electrodes can be identified as A and B or +I and –I to denote source and sink.The potential difference measured as a result of current flow is measured with another pair of electrodes called potential electrodes. These potential electrodes may be represented as M and N, and V will represent the resultant potential difference.

Resistivity = K ($\frac{V}{I}$) where K is a geometrical constant

$$K = \frac{([AB]/2) - ([MN]/2)^2 . \frac{\pi}{2}}{[MN]/2}$$

Where AB = distance between current electrodes
MN = distance between potential electrodes

The changes in the resistivity of geological strata may be measured by a method known as vertical electrical sounding. In the field, a series of resistivity measurements are made at various electrode spacing entered at a common point. Sampling depth is increased by increasing electrode spacing.The M and N electrode array is held fixed while the A and B current electrodes are moved outwardly by constant length. This movement is relative to the increase in depth of measurement as the current electrodes are moved further apart. The depth measured is AB/2. When the current electrodes are moved further apart, the potential recorded from the M and N electrodes will change as the current passes through different subsurface structures.The relationship V = IR (Ohm's law) holds for simple circuits as well as earth materials. However, resistance is not a material constant; instead, resistivity is an intrinsic property of the medium describing the resistance of the flow of current in that medium. In general resistivity is defined as a unit change in resistance scaled by the ratio of a unit cross – sectional area and a unit length of the material through which the current is passing.Earth's resistivity can range over nine orders of magnitude from 1 to 10^8 ohm/m. Table 1 shows the common resistivity of different ground earth types.

Table.1

Material value	Resistivity range	Typical
Igneous and Metamorphic rocks	$10^2 – 10^8$	10^4
Sedimentary	$10 – 10^8$	10^3
Ground Water	1 – 10	5
Pure water		10^3

Common soilresistivity

3. Soilresistivity Processing Circuit

The computation of the resistivity and the subsequent water table results are performed in the microcontroller type PIC 16F877A. The choice of this particular type has been motivated by the fact that it is readily available and reasonably priced. This microcontroller is relatively simply to program; its instructions set has only 35 mnemonics yet performing very powerful operations.

3.1. Measuring resistivity at a depth of 20 meters.

The PIC 16F877A is used to perform the following computations under the control of the program code.The current electrode spacing in this case is 40 meters and the voltage electrode spacing is set at 4 meters, so that:

AB = 40 m
MN = 4m

Plugging these figures into the previously mentioned formula we get:

$$\text{Resistivity} = \left\{ \frac{(40/2)^2 - (4/2)^2 . \frac{\pi}{2}}{(4/2)} . V/I \right\}$$

$$= \left\{ \frac{20^2 - 4 . \frac{\pi}{2}}{2} V/I \right\}$$

$$= 198\frac{\pi}{2}.V/I$$

Taking π to be 22/7 we have 310V/I.

The condition for presence of the water table is that the value of the resistivity should lie in the range of 1 to 10 ohms per meter. Therefore the PIC is programmed to compute the following inequality and display a positive or negative result.

$1\Omega/m < 310V/I < 10\Omega/m$

$= \quad I < 310V < 10I$

The denary number 310 when converted to binary is found to exceed 8 bits in size but the PIC microcontroller registershave got a maximum capacity of 8 bit numbers only. One way to alleviate this is to scale down by 2 so that the inequality becomes:

$\frac{I}{2} < 155V < 5I$

To obtain $\frac{I}{2}$ at the input of the system two resistors in parallel are used as shown in fig 3. This procedure will make the new inequality to be I' < 155V < 10I' where I' is $\frac{I}{2}$

3.2. Measuring resistivity at a depth of 40meters

The procedure for measuring resistivity at the depth of 40 meters is the same as for 20 save for the current electrode spacing which is now 80m but the voltage electrode spacing remains at 4m. In this case AB = 80m.Resistivity becomes 1254V/I and the condition for presence of water remains the same i.e. between 1 and 10 Ω/m. The resulting inequality $1\Omega/m < 1254V/I < 10\Omega$ need to be scaled down to fit into the original range of I' < 155V < 10I' by switching in resistances at the input. Fig. 3 show the implementation circuit diagram of the detector.

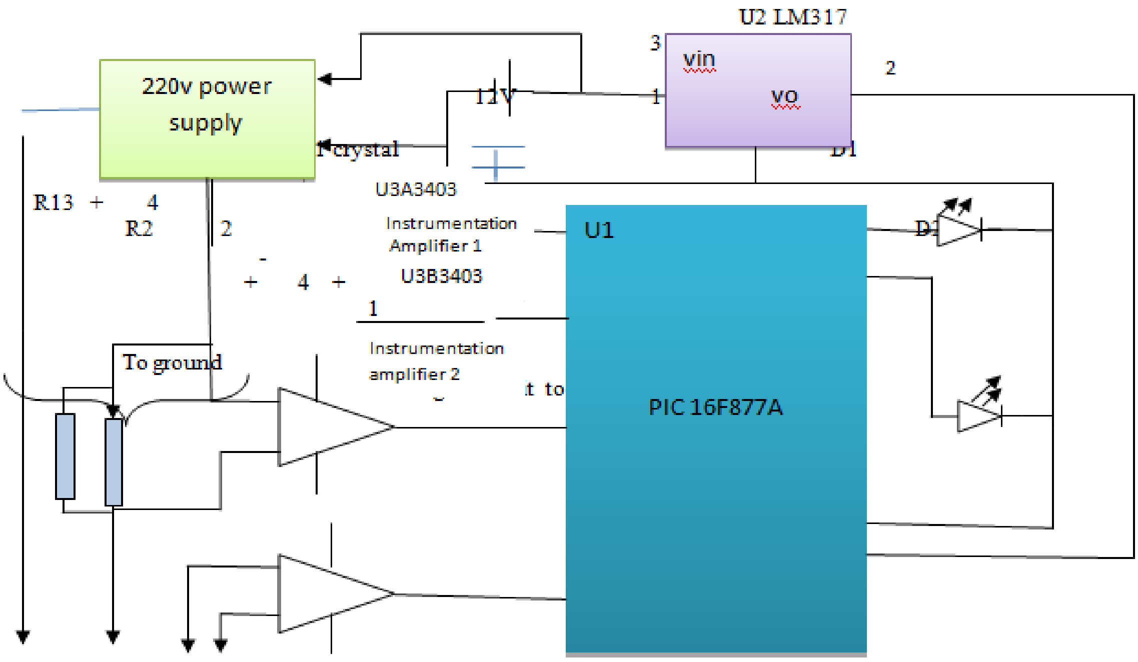

Fig.3.Circuit to measure resistivity

The instrumentation amplifier number 1 samples the value of voltage across the 1.2 kΩ resistors. This gives a value of voltage that is directly proportional to the current passing through the resistor which is also half the current passing through the circuit. The current I/2 is the one used for computing the resistivity by the microcontroller. Instrumentation amplifier 2 measures the underground voltage value. The two values, current passing through the circuit and the voltage across the underground are used to calculate resistivity of the underground structure. Since the groundwater resistivity as shown in table 1 is in the rage of 1 to 10 ohms/m a positive result would be found out if the resistivity of the underground structure lies in this range.Microcontroller receives input voltage and current from which it calculates the resistivity and compares it with known range and gives an output signal to show the presence or absence of the water table. When the device is turned ON, one LED will light at any given moment. As long as the depth of measurement does not contain the water table it means that the red LED will be lighting. The lighting of these LEDs is done in software by the PIC microcontroller.

Fig 4 shows the detailed pin out diagram of the 16F877A microcontroller. The microcontroller makes use of an external clock which, for the purposes of this design uses a 4 MHz crystal oscillator connected to pins 9 and 10. Each instruction cycle takes 1µs to be executed.

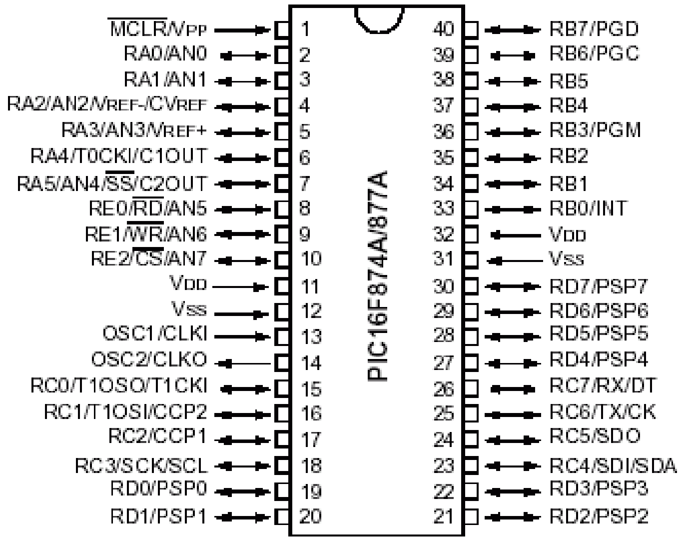

Fig.4. PIC 16F877A microcontroller pin out diagram

3.3 Analogue to Digital conversion

The PIC microcontroller is capable of converting an analogue signal to a digital one. It performs this for one signal at a time. Before the analogue to digital conversion is done there are registers that need to be initialized. These are ADCON0 and ADCON1registers.

3.4 ADCON0 register

The pins for ADCON0 are configured as shown below. This register controls the operation of the analogue to digital module.

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U/O	R/W-0
ADC1	ADCS0	CHS2	CHS1	CHS0	GO/DONE	---------	ADON

Bit 7-6

ADCS1:ADCS0: A/D conversions Clock select bits

00 = FOSC/2
01 = FOSC/8
10 = FOSC/32
11 = FRC (Clock derived from internal A/D module)

Bit 5-3 **CHS2:CHS0: Analogue Select bits**

000 = channel 0 (RA0/AN0
001 = channel 1 (RA1/AN1)
010 = channel 2 (RA2/AN2)
011 = channel 3 (RA3/AN3)
100 = channel 4 (RA4/AN4)
101 = channel 5 (RA5/AN5)
110 = channel 6 (RA6/AN6)
111 = channel 7 (RA7/AN7)

Bit 2 **GO/DONE: A/D Conversion status bit**

If ADON = 1
1 = A/D Conversion in progress (setting the bit starts the A/D conversion)
0 = A/D Conversion not in progress (this bit is automatically cleared by hardware when A/D conversion is complete.

Bit 1 Unimplemented: read as 0

Bit 0 ADON: A/D on bit

1 = A/D converter module is operating
0 = A/D converter module is shut off and consume no operating current.

3.5 ADCON1 Register

This register initializes the control for analogue to digital conversion. The pins for ADCON1 register are configured as shown in the diagram below. The most significant bit selects the analogue to digital conversion format for reading the result. The next four bits are for Port configuration.

R/W-0	R/W-0	U/O	U/O	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	--------	--------	PCFG3	PCGF2	PCGF1	PCFG0

Bit 7 **ADFM**: A/D Result Format Select bit
1 = Right justified. Six (6) most significant bits of ADRESH are read as ‘0’ 0 = Left justified six (6) least significant bits of ADRESL are read as ‘0’

Bit 6 **ADCS2:** A/D Conversion clock select bit

The steps followed when doing the analogue to digital conversion are as follows:

- Configure the A/D module
- Configure pins / voltage reference and digital input output (ADCON1)
- Select A/D input channel (ADCON0)
- Select A/D conversion clock (ADCON0)
- Turn on A/D module (ADCON0)
- Configure the A/D interrupt if desired
- Wait the required acquisition time
- Start the conversion by setting the GO/DONE bit
- Wait for the A/D conversion to complete by either polling the GO/DONE (low) bit or with interrupt enable you wait for the A/D interrupt.
- Read A/D result register pair (ADRESH: ADRESL).

The next page show shows the flow chart of the processes the microcontroller go through to achieve the measurement of the resistivity at 20m depth.

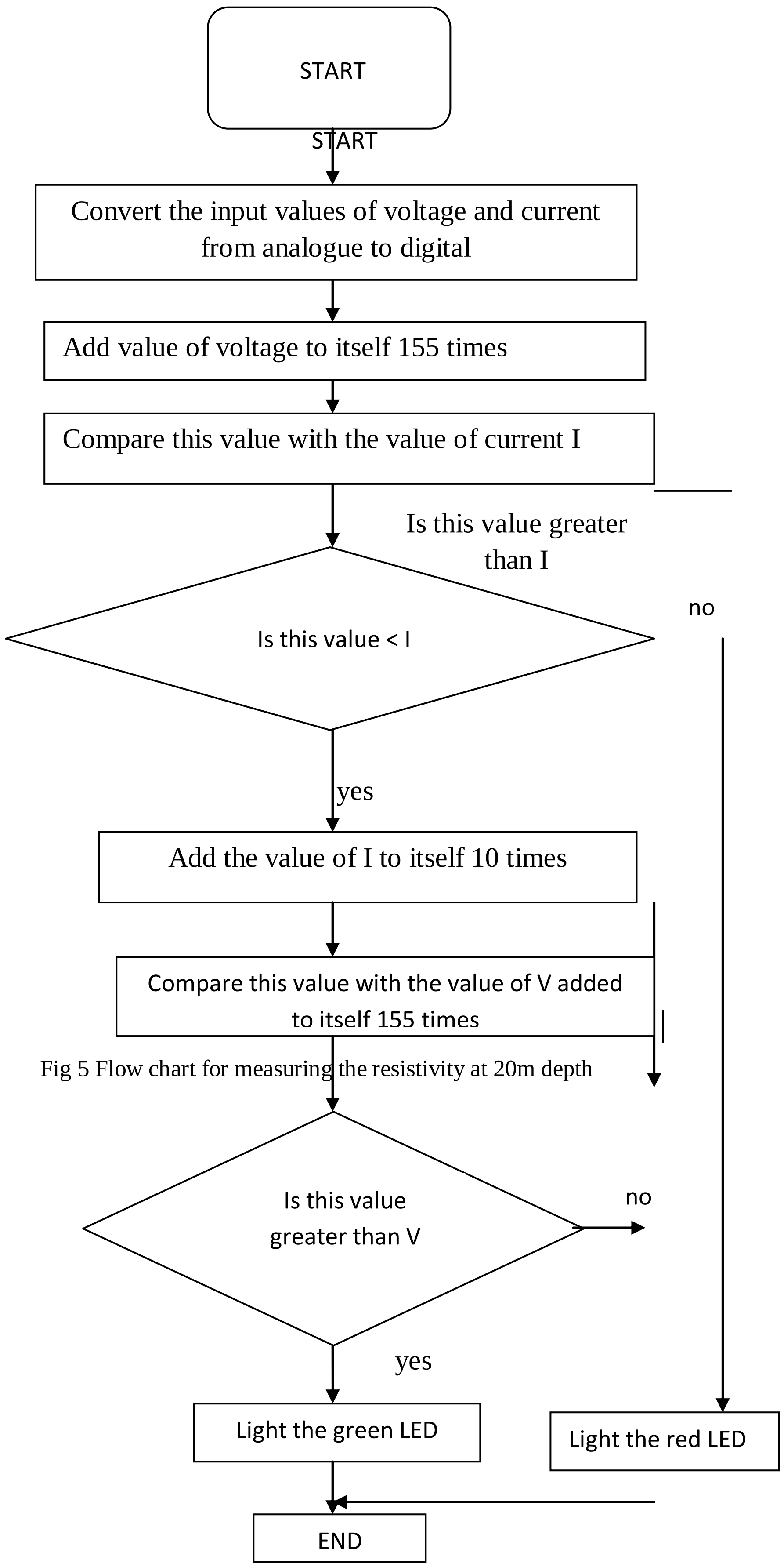

Fig 5 Flow chart for measuring the resistivity at 20m depth

4. Codefor20 M Depth Resistivity

The listing below (listing 1) is the suggested code that controls the operation of microcontroller in the calculation of the resistivity hence the depth of the underground water table.

Listing 1

```
Org 0x00
            RP0         equ     5
            RP1         equ     6

            Vic 1       equ     20h
            Vic 2       equ     21h
            Vic 3       equ     22h
            DEC         equ     23h
            DEC1    equ 24h
            ANS1        equ     25h
            ANS2        equ     26h
            Vic4        equ     27h
            Vic 5       equ     28h
            Vic6        equ     29h
            Init        equ     2Ah
            C           equ     2Bh
            RLED        equ     2Bh
            DEC2        equ     2Ch
            GLED        equ     2Dh
            Cham        equ     2Eh
            STATUS      equ     03h
            INTCON      equ     8Bh
            ADCONO      equ     1Fh
            ADCON1      equ     9Fh
            PORTA equ   05h
            PORTB equ   06h
            ADRESL      equ     9Eh
            PIR1        equ     0Ch

            Org         0x00
            Goto        Main
            BCF         STATUS,RPO
            MOVLW       0x80                ; all analogue input code
            MOVWF       ADCON1
            MOVLW       0x3F
            MOVWF       PORTA
            BCF         STATUS,RPO          ; reset to bank 0
            CLRF        PORTB

Volrcon CALL        SelAN0
            CALL        AtoD
            CALL        Volt

            Return
Currcon CALL        SelAN1
            CALL        AtoD
            CALL        Curr

            return

SelAN0 MOVLW        b'01000001'
            MOVWF       ADCON0

            Return
```

```
AtoD        BSF         ADCON0, 3
Z           BTFSS       PIR1, 6
            goto        Z

            return

Volt        MOVF        ADRESL, W
            MOVWF       vic1
            MOVWF       vic2

SelAN1 MOVLW      b'01001001'
            MOVWF       ADCON0

            return

Curr        MOVF        ASRESL, W
            MOVWF       vic4
            MOVWF       vic5
            MOVWF       vic6

            return


Cham        Banksel  ADCON1
            CLRF        ADCON1
            MOVLW       b'01000001'
            Banksel  ADCON0
            BCF         INTCON, 7
            return
main
            CALL        Cham
            CALL        Voltcon
            CALL        Currcon

            MOVLW       0xFF
            MOVWF       DEC
            MOVFW       vic1

x           ADDWF       vic2, 0
            DECFSZ      DEC
            GOTO        x
            MOVWF       vic3
            MOVLW       b'00111000'
            MOVWF       DEC1
            MOVFW       vic3

y           ADDWF       vic2,0
            DECFSZ      DEC1
            GOTO        y
            MOVWF       ANS1
            MOVFW       vic4
      SUBWFANS1,1  ;ANS1-vic4
            BTFSC  STATUS,C
            GOT         RLED
            MOVLW       b'00001010'
            MOVWF       DEC2
            MOVFW       vic5

A           ADDWF       vic6,0
```

```
DECFSZ        DEC2
GOTO          A
MOVWF         ANS2
SUBWFANS1,0
BTFSC  STATUS,C
GOTO          GLED
GOTO          RLED
END
```

5. High Voltage Power Supply

In order to make the device truly portable the necessary 220 volt supply must be generated from the 12volt battery. The power supply schematic is shown in fig. 6. To keep the cost of the device low readily available components that are not highly specialized have been chosen. The NE555 timer has been used to generate a high frequency that derives Q1 and Q2 which in turn derives the transformer Tr1. The output voltage is then available across terminals 3and4 of Tr. 1.

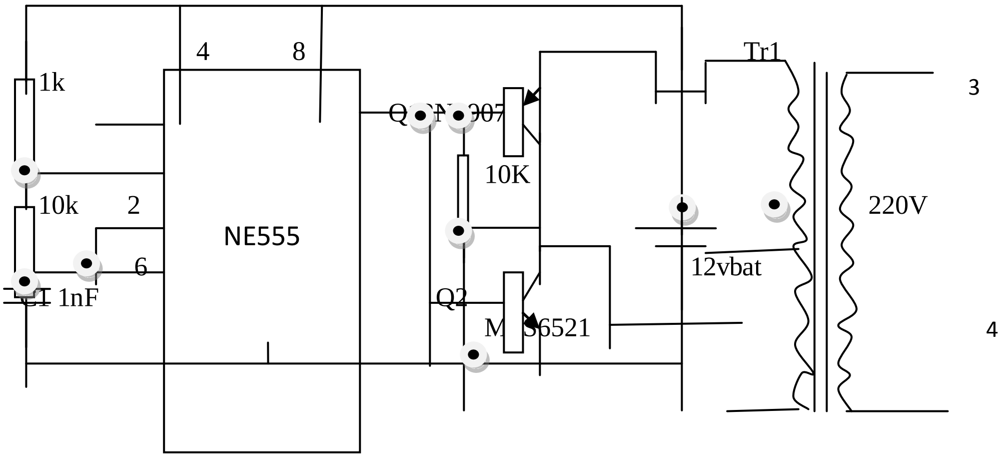

Fig.6 High voltage power supply

With the timing components given the NE 555 timer generates a square wave at a frequency, 68 kHz. The output pin 3 of the timer is fed onto the transistors. A high output which is 2/3 of the supply voltage causes transistor Q2 to conduct while transistor Q1 is not conducting. This is because Q2 is active high transistor. A low at the base of Q1 ensures conduction of this transistor.The 68 kHz value was chosen to minimize the size of the transformer as well as conserving power consumption from the battery making the device truly portable.

6. Conclusion

The design of a water table detector as shown here provides for an alternative way of constructing and production of a cheap and effective underground water table detector that is affordable, portable and can be useful in rural settings. This has been achieved by use of compact components such as the microcontroller, the NE555 timer and a high efficient transformer. The design is centred on three major components i.e. the PIC microcontroller, NE 555 and the program code. Further refinements in terms of packaging can make this device truly portable. The design objective is to provide for a simple and portable underground water detector that can be used by less sophisticated persons and this paper has successfully presented a possible solution to this end. Improvements to this device could be in making high voltage power supply that is more robust, by use of specialized components. However in so doing care must be exercised to avoid over pricing of the end device.

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