MICROPROCESSOR CONTROLLED MILDEW DETECTOR

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Abstract

Downy Mildew is a vineyard disease which has cost the Economy tens of millions of rand in terms of both harvest loss and pest control measures. However, the weather conditions conducive to an outbreak of the disease have been well researched, thus it should be possible to monitor these in the vineyard and subsequently raise an alarm, whereupon systematic application of fungicide agents should prevent an outbreak of the disease. The work presented describes a Microprocessor based Monitor/Alarm system whose purpose it is to alert the farmer to an imminent outbreak of Downy Mildew.

Acknowledgements

My sincere thanks are due to:

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List of Symbols

b	-	binary
d	-	decimal
f	-	frequency
h	-	hexadecimal
loc	-	storage location in Microcomputer memory
t	-	Clock period of the Microprocessor
T	-	Elapsed time, periodic time of a wave

1. BACKGROUND

Jan van Riebeeck planted the first vine at the Cape in 1655, but more recently a formidable enemy has appeared on the scene. Downy Mildew is a fungus which befalls the leaves of grape vines. The leaf withers, dies and falls to the ground, but not without having spawned another generation of fungus spores which by the millions are now ready to attack the entire vine= yard.

With Photosynthesis having stopped the young grape bunch is deprived of its source of energy; it withers, dies and falls to the ground, Figs. 1a, b. At worst the entire plant can be lost.

Fig. 1a The Result of a Downy Mildew Attack

Fig. 1b Downy Mildew: The Plant might survive
-The Harvest is lost

Downy Mildew (of Donsskimmel as dit in Afrikaans bekend staan) was found in Europe already in the 19th century. In South Africa it first occured in 1907 in the Eastern Cape, it spread to the Transvaal and then Natal and in 1968 the Western Cape, where most of the country's grapes are grown, was hit for the first time.[1)] Downy Mildew can be fought but not eradicated, in the opinion of the experts. It is here to stay.

Out of respect for the disease, many farmers spray fungicides at considerable cost many times during the season - and possibly at times unnecessarily! Others, either because they don't know when to spray or because they have adopted a fatalistic attitude, don't spray at all. The Mildew Detector described here, if successful, will allow the farmer a more systematic and efficient approach in the fight against Mildew. This will lead to improved economy both in terms of saved fungicides and saved crops.

2. DOWNY MILDEW - BIOLOGICAL FACTS

In order to establish a base line for the fight against the disease, it is necessary to review briefly the life cycle of this parasite in the hope to detect a weak spot for attack.

Within the plant kingdom Downy Mildew belongs to the Division of the Fungi. These are characterised by the absence of chlorophyll: incapable of producing organic substances from anorganic compounds they depend on green plants for food and this makes them Parasites.[2)] Mildew thrives in damp and warm conditions and is particularly well equipped for survival, multiplication and dispersal. Thus, after a period of rest during which climatic conditions are not favourable a vineyard can still experience an outbreak of epidemic proportions.

Fungi are capable of sexual as well as asexual repro= duction! After a period of vegetative growth during the summer months and one or several cycles of asexual reproduction male and female cells are formed within the host tissue which fuse to form Oospores or "Winter spores". These "resting spores" can survive within the leaf or in the top soil on the ground for many months. In springtime, when average temperatures rise above 10^{o} C and water is simultaneously available for at least 2 to 3 days the Resting Spores come back to live. In the Western Cape these conditions generally arise in the month of September, please refer Figs. 4.,5. The Winter Spores now germinate and release Zoospores or "Swarm Spores" into surrounding free water.

Here is our first chance for attack: if we poison the free water on the ground and on the young spring leaves with fungicide we can kill the swarm spores and thus disrupt the parasite's life cycle!

We must therefore detect the condition "Temperature equal or greater 10^{o}C and simultaneoús free water for 2 days",[1)] raise an alarm and spray immediately.

By "free water" we shall mean any water available as sheet, drops or tiny droplets on the surface of solids as opposed to airborne water in the form of vapour or mist.

Swarm spores, so called because they have flagellata or "whips" attached for propulsion, can enter the leaf on the underside through minute openings, for the leaf is not a solid mass of cells. It is interspersed with tiny pockets of air and those near the under surface are open to the outside world.

"Primary Infection" has now taken place. After an Incubation Period of about 2 weeks symptons become visible: first yellowish oil-like spots on the upper side of the leaf, Fig. 2, then the fungus grows out of the leaf on its underside, forming a downy white weft, Fig. 3. This is the sign of a profusion of Conidia or "Summer Spores". They are minute and very light and are carried by water and wind everywhere. Should they land on an obligate host e.g. another vine leaf, then there is imminent danger of "Secondary Infection"! Asexual multiplication now sets in.

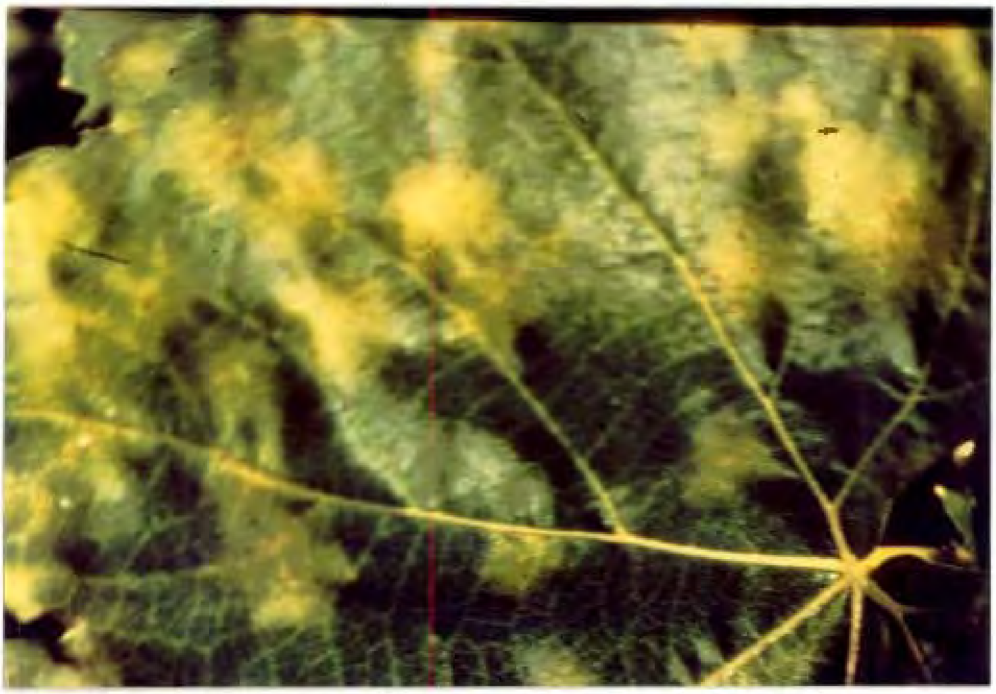

Fig. 2 Symptoms: Yellow Spots on the Upper Side of the Leaf

Fig. 3 Symptoms: A white downy Weft of Spores on the Underside of the Leaf

For germination and the forming of Swarm Spores to take place temperature needs to be in an acceptable range, say between 7° C and 29° C, for only one hour, with concurrent free water for 3 hours.[1)] The Swarm Spores will enter the intercellular space and after an incubation of as little as 3 days, the yellow oil-like specks appear on the upper side of the leaf.

Therefore we must detect "Temperature 7° C ... 29° C for one hour with simultaneous free water plus an additional 2 hours of free water with temperature then being fairly irrerelevant", raise alarm and spray immediately.

One must remember that it is now summer and it is interesting to note that by means of irrigation the farmer can unwittingly supply the free water for successful germination!

If Secondary Infection is allowed to continue a white wheft grows on the leaf's underside, evidence of a new generation of Summer Spores, ready to become air and waterborne for another asexual Secondary Infection cycle, and so on!

In autumn (March in the Western Cape) weather conditions become less favourable, vegetative growth is curtailed, male and female nucleĭ develop within the host tissue and these combine to form the Winter or Resting Spores once more.

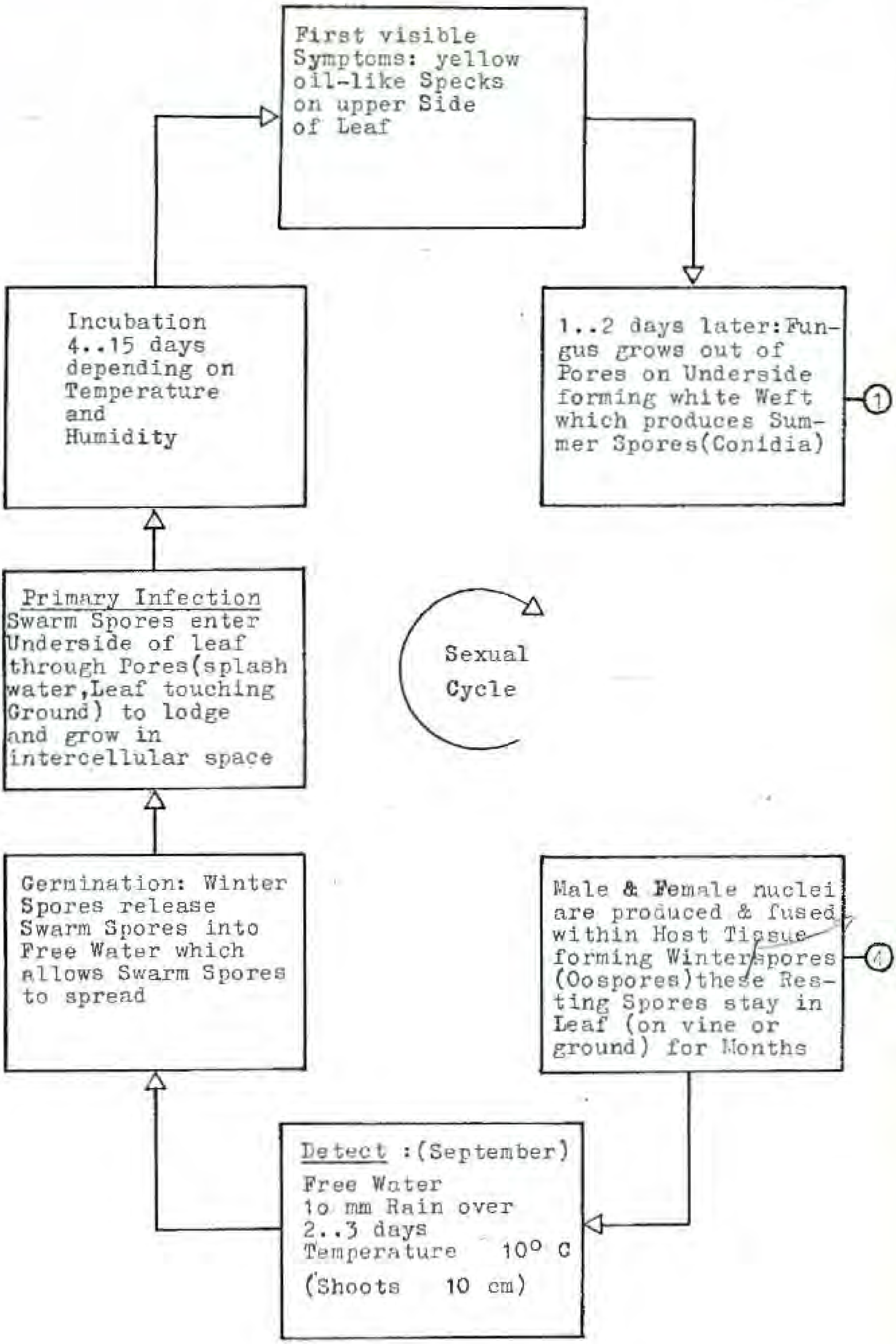

Fig. 4 Downy Mildew: Life Cycle

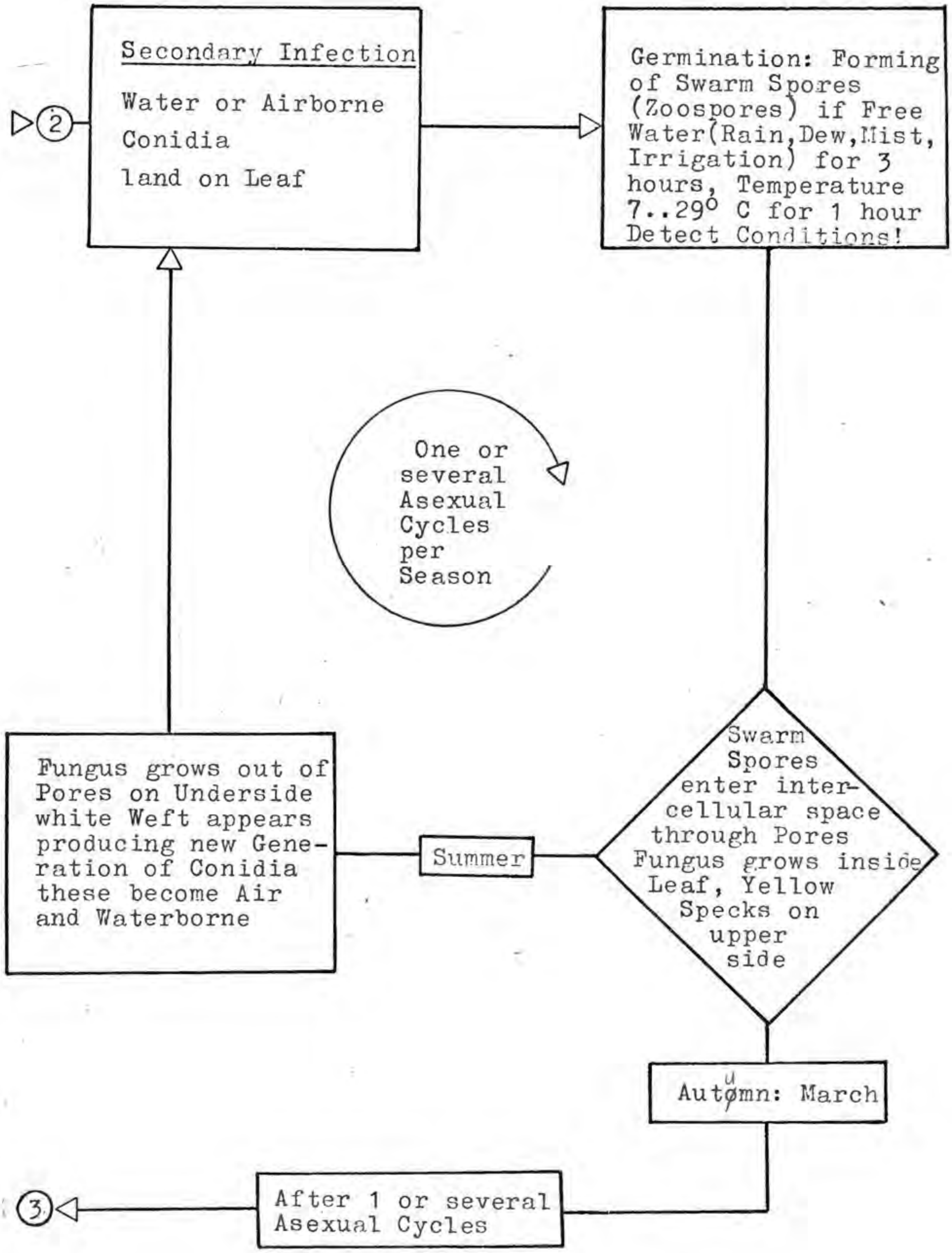

Fig. 5 Downy Mildew: Life Cycle continued

A question one might ask is: should the humidity level be monitored as well? Both Primary and Secondary Infection require that swarm spores enter the leaf through the pores. They can only do this when they are mobile. For mobility they need free water since they propel themselves by movement of their (2) flagellata. (High) humidity will merely extend the length of time for which free water is available, but it is sufficient to monitor the free water itself!

Having established by this brief botanical review What must be done to combat the disease, we now can proceed to show How our goal might be achieved by electronic means.

3. DOWNY MILDEW - ELECTRONIC COUNTERMEASURES

The Electronic Monitor/Alarm System which will detect the conditions set out above could be essentially analog, digital or hybride. For an analog approach one might have temperature and water sensors feeding into comparators whose reference imputs correspond to the thresholds to be detected. The comparators would trigger timers which, after the appropriate delay, would trigger the alarm. Even if it could be assumed that timing accuracy and precision based on RC time constants would be adequate for botanical work, a digital approach based on a Microprocessor has the great advantage of combining accuracy, precision and flexibility. Flexibility is especially important in a new instrument of this kind where during the experimental phase the researcher wishes to change delay times and water and temperature references fast and reliably, with ease of a key stroke. This comfort has its price: a special effort has to be made in a discipline still new to many electronic designers: Software Engineering.

3.1 A Microprocessor based Monitor/Alarm System

Intel's System Design Kit SDK-85 was chosen for the project. It is both a complete Microprocessor System ("Microcomputer") and a miniture Development System[6,7,8], (hereafter refered to as the "8085"), see Fig. 19. The Kit contains a ROM based Monitor enabling one to load and debug a Machine Language Programme.

A Microprocessor System is a fairly complex piece of equipment. Therefore an attempt was made to let the system do as much work as possible and minimise any additional external hardware. Fig. 6 shows a block diagram of the proposed system.

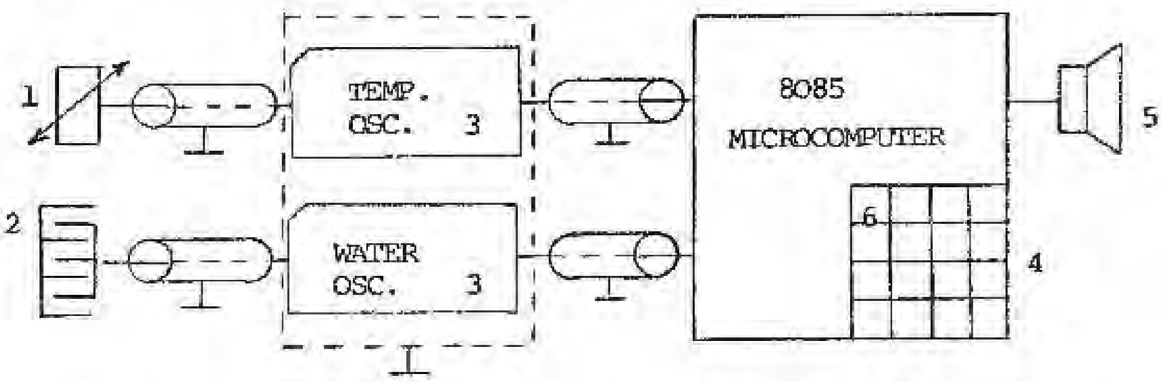

Fig. 6 Block Diagramme of proposed Monitor/Alarm System

1 TEMPERATURE SENSOR
2 WATER SENSOR
3 VARIABLE FREQUENCY OSCILLATORS
4 KEYPAD FOR ENTRY OF PARAMETERS
5 ALARM (BELL, SPEAKER)
6 ALARM RESET BUTTON

The Temperature and the Water Sensor each vary the frequency of an oscillator. The varying periodic times are constantly measured by the Microcomputer and compared with internally stored references. The Microcomputer triggers an Alarm when conditions such as set out in section 2 above are obtained. The Alarm can only be stopped by pressing a RESET button, forcing the operator to pay attention. The oscillators make use of a 556 Dual Timer IC in its astable mode. The output wave is rectangular. The advantages of this wave shape are twofold: they are most easily produced and their periodic time is more reliably measured by a digital system because of the rapid transition between the two logic levels, in contrast to, e.g., a sine wave.

To reduce the possibility of random errors it is advisable to measure the Periodic Time over many cycles, not just one. 256 cycles were chosen, this corresponds to the count range of an 8085 8 bit register. (For experimental purposes this figure can easily be changed by a single programme instruc= tion.) The total time of these 256 waves is stored in a 16 bit register pair and it is obvious that the register pair will overflow if the frequency is chosen to low, in fact, at a frequency of 363 Hz the register content is FF77h, giving a practical lower limit of 400 Hz. (These figures are derived in section 3.3.4.)

The Temperature Sensing Oscillator

The frequency of oscillation is given by

$$f = \frac{1,44}{C(R_A + 2R_B)} \qquad (1)$$

and the duty cycle is given by

$$D = \frac{R_B}{R_A + 2R_B}$$

, please refer to Fig. 7

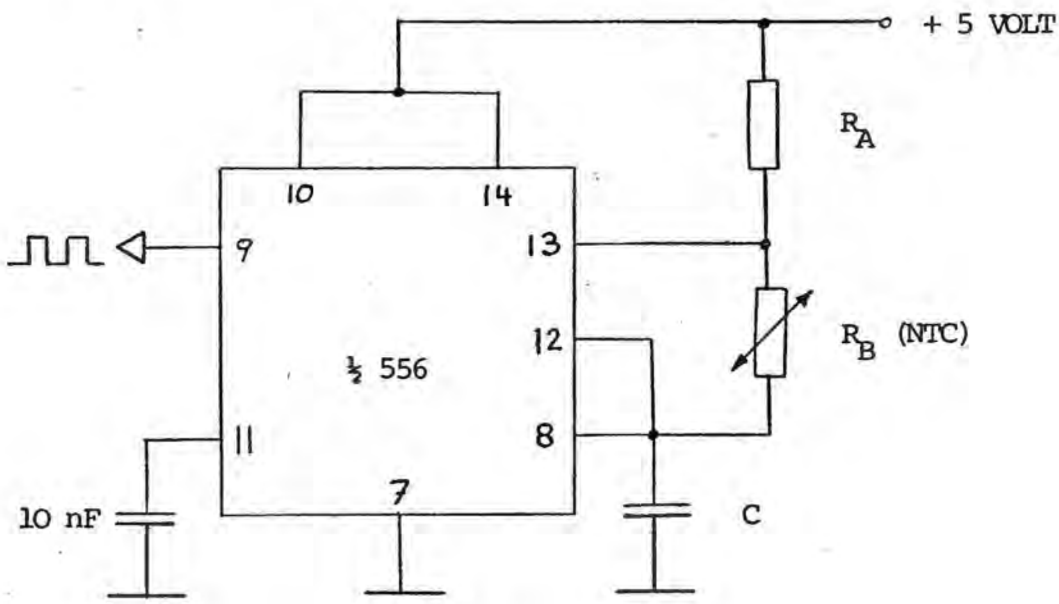

Fig.7 Temperature Monitoring Variable Frequency Oscillator

A natural choice for our application would be a square wave, D = 0,5 and $R_A = 0$. In practice it was found however that with $R_A = 0$ the circuit can fail to oscillate. With R_A = 560 Ohm no problems are experienced.

The temperature sensor is a Negative Temperature Coefficient (NTC) Thermisitor, type F14D, made by ITT. Its published characteristic is shown in Fig. 8.

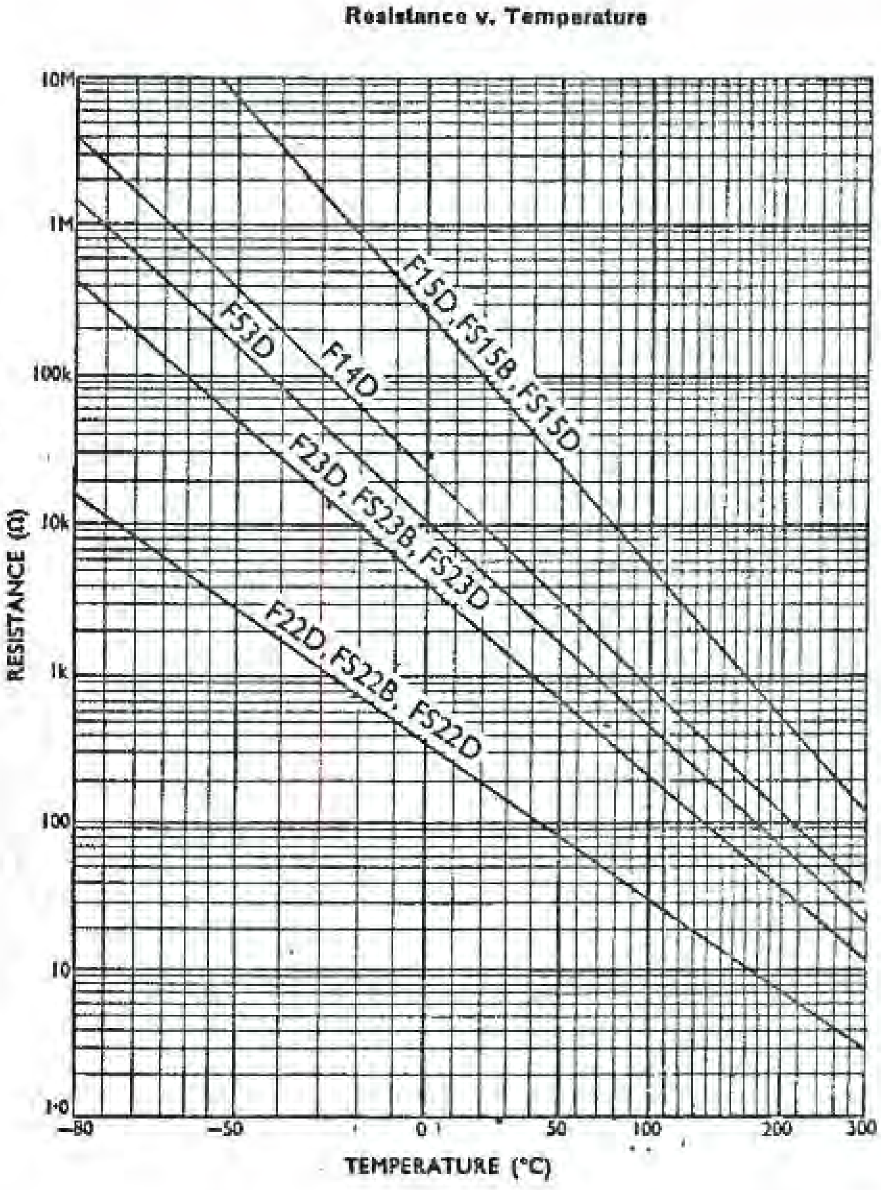

Fig. 8 Resistance vs. Temperature Characteristic for the selected Thermistor F 14 D and others. The Plots indicate "typical" Values.

Its measured characteristic over the temperature range of interest is plotted in Fig. 9. At 30^{o} C the resistance is approximately 7 kOhm, giving a worst case duty cycle

$$D = \frac{7}{0,56 + 2x7} = 0,48$$

This small deviation from a square wave poses no measurement problem. Only a very small D of the order of 0,01 might pose a problem in as much as the resulting needle pulse might be missed by the programme loop which tries to measure its width.

We can now culculate the timing capacitor C with

f_{min} = 400 Hz

R_A = 560 Ohm

R_B = 25 kOhm = R_{BMAX} at 0^{o} C say, (coincides with f_{min})

From (1)

$$C = \frac{1,44}{f(R_A + 2R_B)} = \frac{1,44}{400\ Hz(0,56 + 2x25)kOhm} = 71,2\ nF$$

<u>The Water Sensing Oscillator</u>

For this oscillator the capacitance is formed by the Water Sensor (described in section 3.2). When water is present on the sensor its capacitance is increased, the frequency is reduced. The measured capacitance of the dry sensor is 28 pF. For frequencies similar to those of the Temperature Sensing Oscillator (approxi= mately 1 kHz) this leads to high resistance values of approximately 25 MOhm. In practice this low C/R ratio

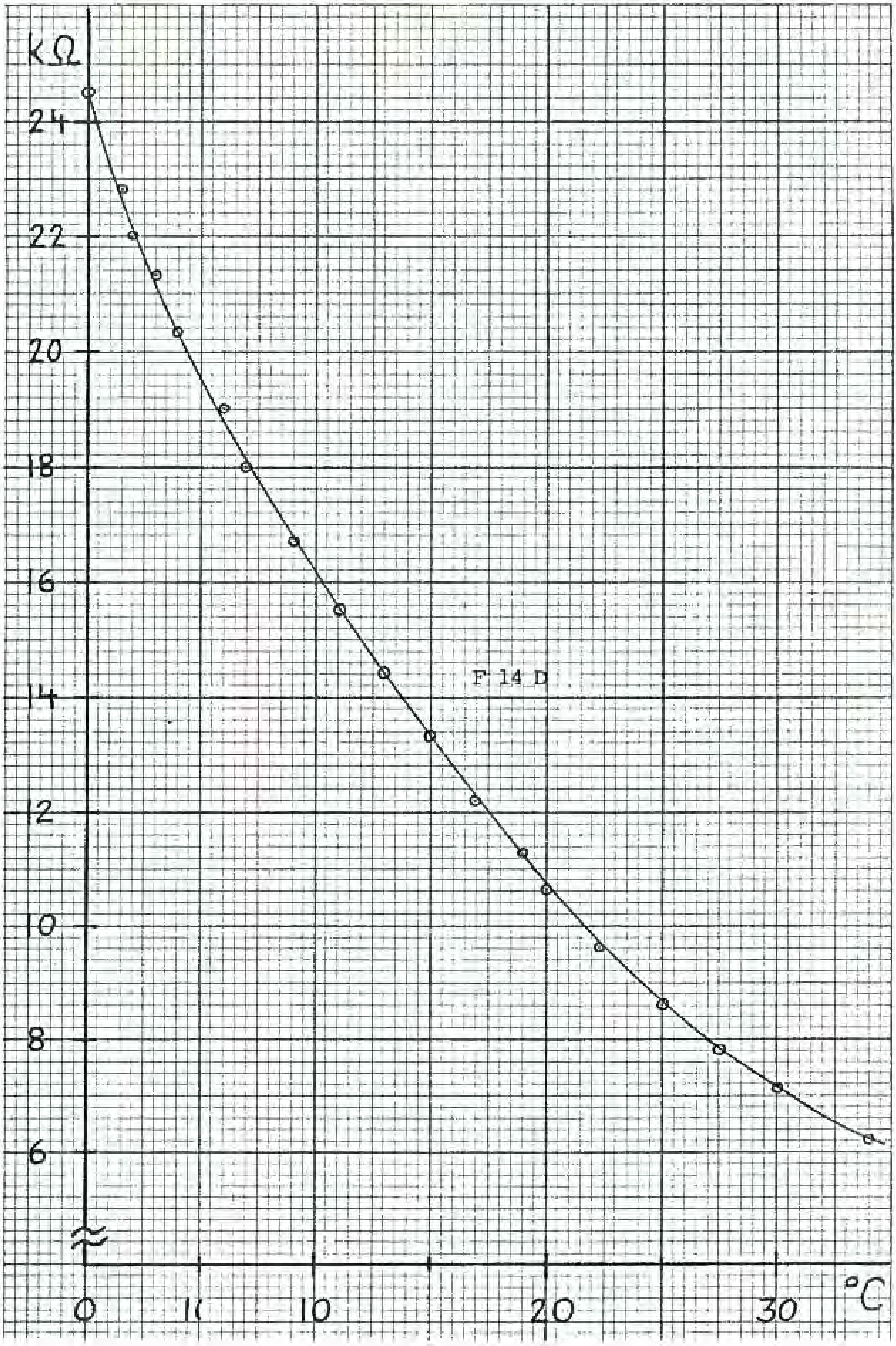

Fig. 9 Measured Characteristic of a Thermistor F 14 D over the Temperature Range of Interest

caused a noticable phase jitter. At 3 kHz (reduced R) no jitter was noticable. A design value twice as high, i.e. 6 kHz, was chosen. (Raising the frequency unnecessarily high reduces the accumulated count in the Periodic Time Register, increasing the chance for random errors).

With R_A = 3,9 kOhm ($R_A \neq 0$ for save oscillation and $R_A \ll R_B$ for rectangularity) and C = 28 pF + 10 pF wiring and stray capacitance we obtain from (1)

$$R_B = \tfrac{1}{2}\left(\frac{1,44}{fC} - R_A\right) = \tfrac{1}{2}\left(\frac{1,44}{6000\ \text{Hz} \times 38\ \text{pF}} - 3,9\ \text{kOhm}\right)$$

$$= 3,16\ \text{MOhm}$$

A 3 MOhm resistor was chosen giving a measured "dry" frequency of 5500 Hz.

A metal film resistor was selected for its low tempe= rature coefficient and superior stability. The circuit is shown in Fig. 10.

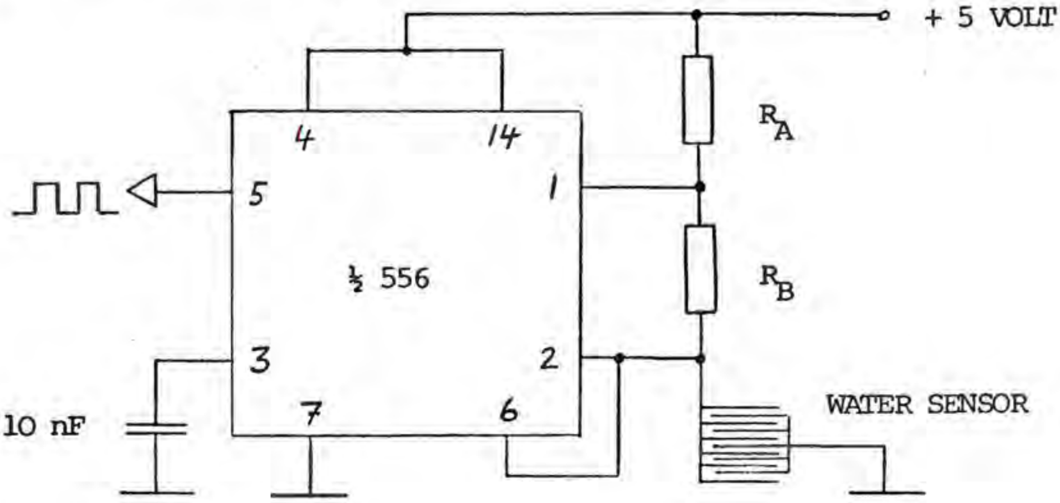

Fig.10 Free Water Monitoring Variable Frequency Oscillator

When the entire sensor surface is covered with a sheet of water capacitance is 64 pF, giving calculated and measured frequencies of 3241 Hz and 3000 Hz, respecti= vely. A minute droplet, barely visible with the naked eye causes a capacitance change of +dC = 0,1 pF (measured with HP Digital Impedance Bridge). Differen= tiation of (1) gives the resulting frequency change as

$$df = - \frac{1,44}{(R_A + 2R_B)\ C^2} \cdot dC \qquad (2)$$

$$= - 17 \text{ Hz}$$

The important question however is: what count differen= tial dX is caused in the Register?

If we differentiate the expression for the count X (derived in section 3.3.4) with respect to frequency we obtain

$$dX = - \frac{Y}{33 \times t \times f^2} \cdot df$$

where Y = number of cycles counted (here 255)

t = clock period of Microprocessor

substituting (2) and (1) gives

$$dX = \frac{YdC}{33 \times t \times f^2 \times C} \cdot \frac{1,44}{C(R_A + 2R_B)}$$

$$= \frac{YdC}{33 \times t \times f \times C} ,$$

where f and C are interrelated by (1), giving finally

$$dX = \frac{YdC}{33 \times 1,44 \times t} \cdot (R_A + 2R_B) \qquad (3)$$

$$= 10$$

If we consider that a digital machine can produce a response (Alarm) for a dX = 1 we appreciate the considerable sensitivity of the instrument! However we must be realistic. There will in practice be small uncontrollable frequency drifts - if only due to acumulating dust on the sensor - forcing us to introduce a "guard band" to avoid false alarms. A guard band of 10 counts gave consistantly reliable results under laboratory conditions, making the tiny droplets described above just about the smallest amount of water detectable. However, formula (3) clearly points the way to increased sensitivity should this be desired, i.e. we must increase Y, the number of cycles counted! Increasing R_B is not advisable because of the phase jitter already mentioned, and increasing dC has physical and technological limits. In the short term one may of course make the guard band quite small and it is interesting to note that just exhaling moist air onto the sensor will then trigger the alarm.

Adjustment of both Y and the guard band is a simple operation in a programme controlled digital device. Please also refer to section 4. Using the Mildew Detector - a Practical Viewpoint.

Fig. 11 shows how the outputs from the two oscillators must be connected to the Microprocessor input ports.

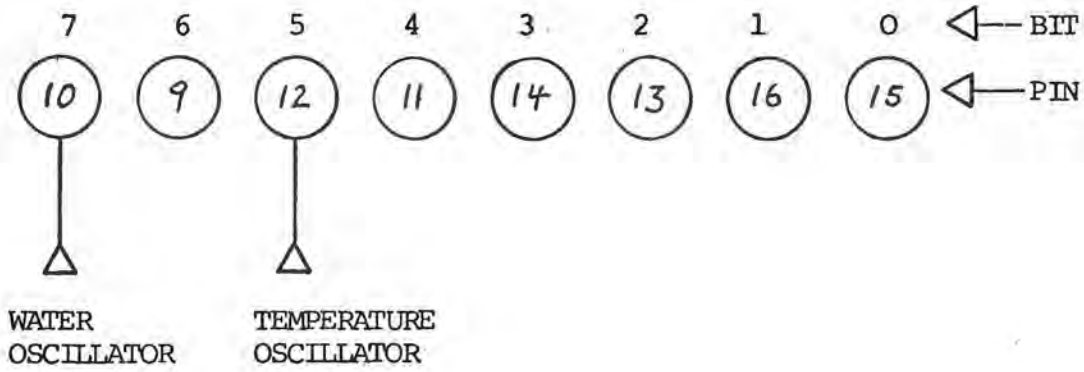

Fig.11 Connection of Water and Temperature Frequencies to PORT 0 of the 8085 Processor

Fig. 12 indicates where the alarm must be connected to the output port of the Processor.

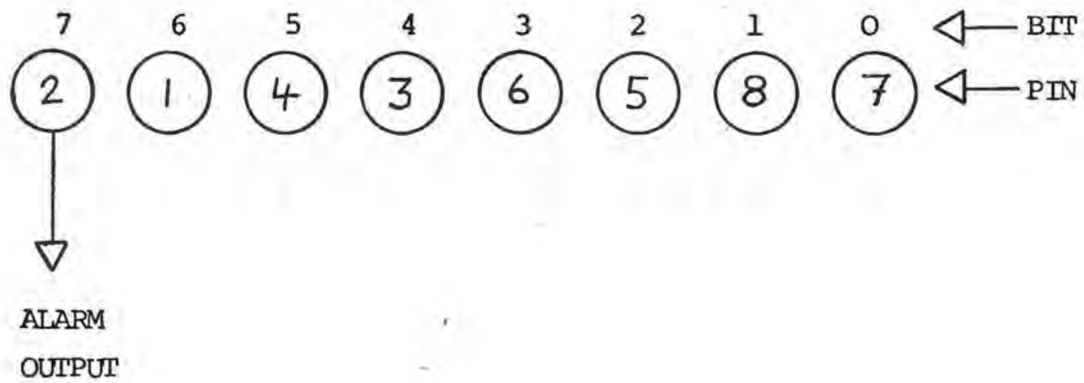

Fig.12 Alarm Output is taken from Pin number 2 PORT 1

The Ports and Pin numbers mentioned above are clearly marked on the 8085 Printed Circuit Board.

A single Common Emitter stage drives a small sonar Alarm. This stage can source or sink 800 mA. A high powered Alarm for a vineyard could be driven via a power Darlington Transistor, as suggested in Fig. 13.

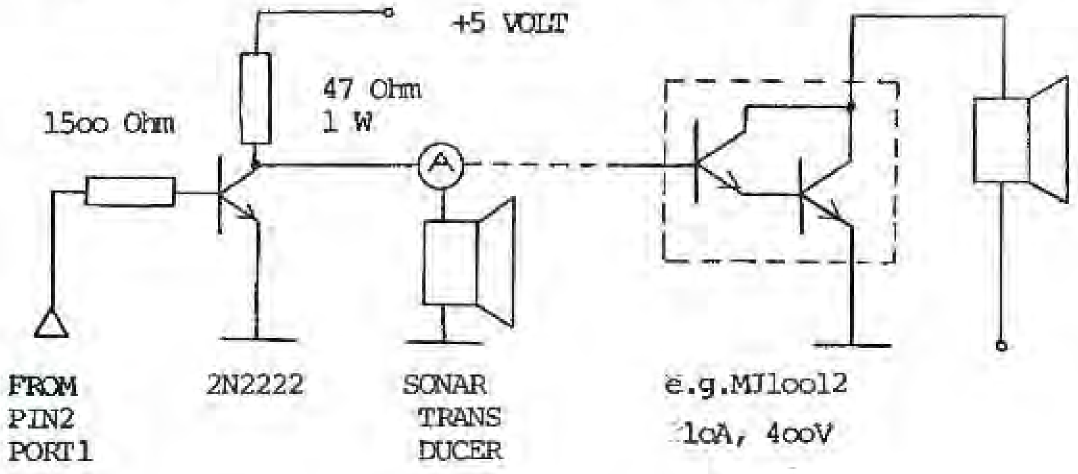

Fig.13 Alarm Drive Circuit. Shown to the right of point A is a suggested Addition should a High-Power Alarm be required.

The Alarm output from the Processor is a penetrating 1600 Hz square wave so that a powerful loudspeaker, preferably a folded-horn type for outdoor use, can be driven directly from the power Darlington Transistor, no extra power oscillator is needed.

3.2 <u>Free Water and Temperature Sensors</u>

A capacitive type <u>Water Sensor</u> was chosen. An inter-digital comb structure is printed on a fibre glass board, as shown in Fig. 14. The structure is covered with a very thin plastic film, to exclude the less reliable conduction component. The film, having a dielectric constant > 1 acts unfortunately somewhat as a screen for electric fields, it should therefore be as thin as possible. Fortunately the ratio of the permitivity of water to that of air is large (81) so that a measurable capacitance change is still produced by tiny droplets, as discussed in section 3.1 above.

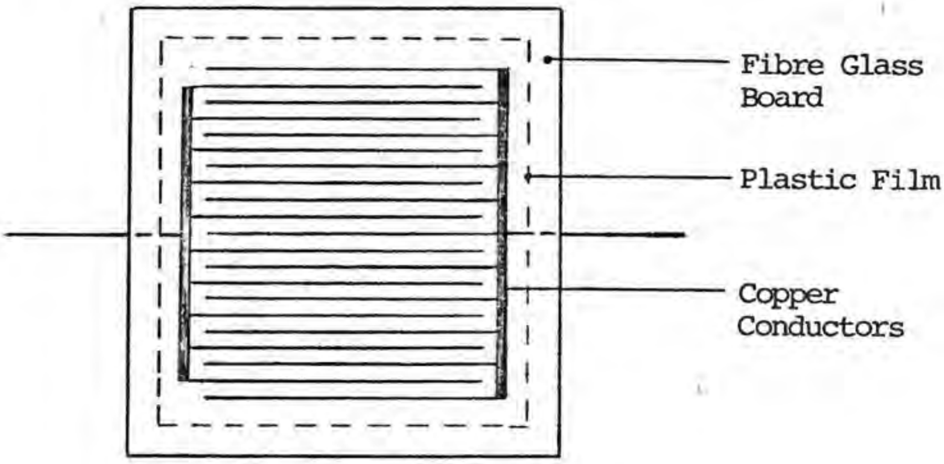

Fig. 14 Plan View of Free Water Sensor showing Interdigital Comb Structure of Copper Conductors

Fig. 15 indicates the detrimental effect of the film on the electric field. The film keeps the water out of the zone of high flux density. For best results (large dC) the permitivity of both film and substrate should be as low as possible. A ceramic carrier with fired-on thick film conductors is likely to give better results.

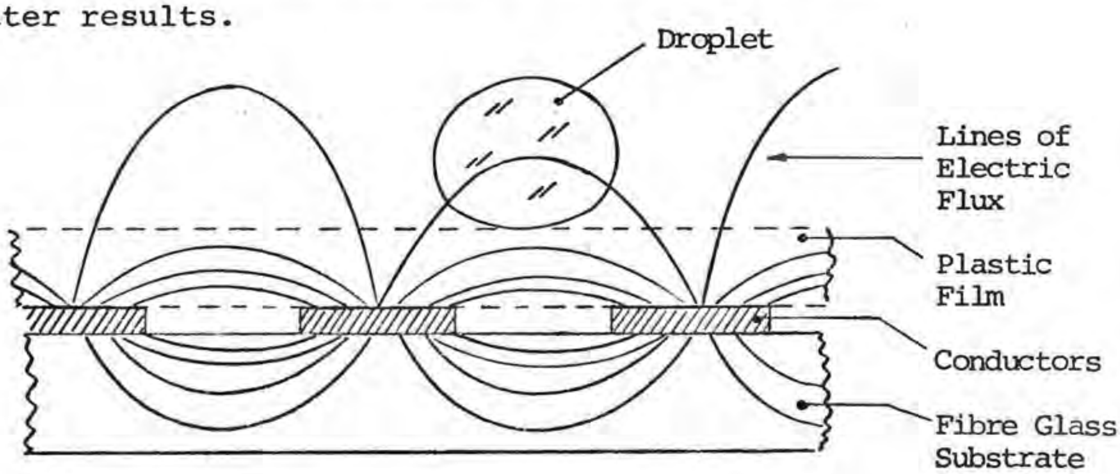

Fig. 15 Section through Water Sensor showing estimated Estimated Electric Field Distribution

Fig. 16 shows the original mask produced for the sensor along with a 4 : 1 reduced version for etching the sensor board. The smaller geometry allows improved registration of minute water droplets.

Fig. 16 Original Sensor Mask and 4:1 reduced Etching Mask

There are of course alternative ways to monitor moisture: the hygroscopic Lithium-Chloride based Dunmore Cell, the Anodized Porous Aluminium Oxide Sensor, Microwaves etc. However, most alternative methods are more suitable to measure relative humidity rather than actual wetness, the associated circuits can be complex and the sensors expensive! In contrast, the Capacitive Interdigital Comb suggested here is inex= pensive, easy to manufacture and unaffected by prolonged exposure to water. A photograph of the sensor is shown in Fig. 17.

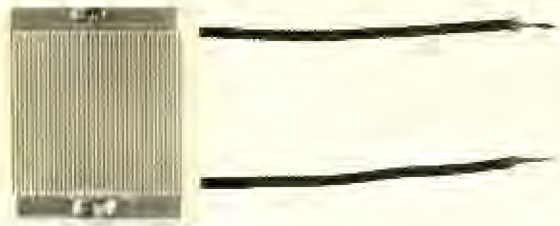

Fig. 17 The Water Sensor used as Leaf Wetness Detector (actual size)

Numerous options exist for the sensing of Temperature, some of which are: Temperature Dependant Resistance (NTC or PTC)

Thermocouples

Forward voltage drop of a p-n junction diode

Intergrated circuit sensors, etc.

The latter, e.g. National's LM335 or Texas' TSU102, have a linear output but a small temperature coefficient of approximately 0,7%/K. The same argument holds for p-n junction diodes. The main draw back of the thermocouple is its price and low output voltage.
NTC's on the other hand have temperature coefficients of the order of -5% and produce a large output signal, but output is nonlinear with respect to temperature. Since we do not wish to construct a thermometer but merely must establish the limits of a temperature band (viz. 7 to 29°C) linearity is not of great concern. More important is a large gradient at the band edges. Further, a large output signal and simple hardware configuration would be an asset. Thus our choice is a

Temperature Dependant Resistor. An NTC type was selected: F14D, glass encapsulated

Temperature coefficient a_{20} = -4%/K

Nominal resistance at 25^{o}C = 8200 Ohm

The resistance vs. Temperature Characteristics were shown in Figs. 8 and 9. The specifications of NTC's are usually subject to considerable tolerance neces= sitating recalibration when a different specimen with the same type number is used. However, Yellow Springs Instrument Co. Ohio, USA, produce "precision inter= changeable thermistors" with tolerances of a fraction of one percent.

Because of the inherent flexibility of a software controlled instrument a Thermistor of almost any description could be accommodated.

3.3 Programming the Microcomputer

This activity soon proved to be the major task of the entire project, possibly because of the writer's non-familiarity with software engineering. The programme was written in Assembly Language, it was then hand-assembled into Machine Language, and entered into the processor's RAM memory via the keyboard. Then follows the inevitable debugging process..!

A complete programme listing is given in Appendix A.

Assembly Languages are processor oriented. Thus one is forced to pay a good deal of attention to the interior machine architecture. One constantly deals with the machine on the register level and has to keep track of which registers are available at any given time and whether they are 8 or 16 bits wide. At all times one must be aware of the contents of the Status Register to exploit it to best advantage. A diagram showing the Register Structure of the Microprocessor is given in Fig. 18, an overall block diagram of the 8085 Micro= computer is shown in Fig. 19. A detailed description of the 8085 is given in the literature supplied by the vendor[6,7,8].

We established in section 2, Biological Facts, WHAT must be done. Now we have arrived at the crucial point: the HOW!
To get ones ideas ordered a Flow Chart - a graphical respresentation of the steps required to obtain a solution - is a good start.[x)]
We tackle the programme for Secondary Infection first. A portion of this we can then re-use for the detection of Primary Infection.

3.3.1 The Secondary Infection Programme

The task: trigger an Alarm when
temperature in range $7^{\circ}C \leq$ Temperature $\leq 29^{\circ}C$
for $\geq$ 1 hour, and simultaneously
Free Water available for $\geq$ 3 hours.

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x) This is akin to the "Block diagram" of the hardware designer, his detailed circuit diagram is our programme code!

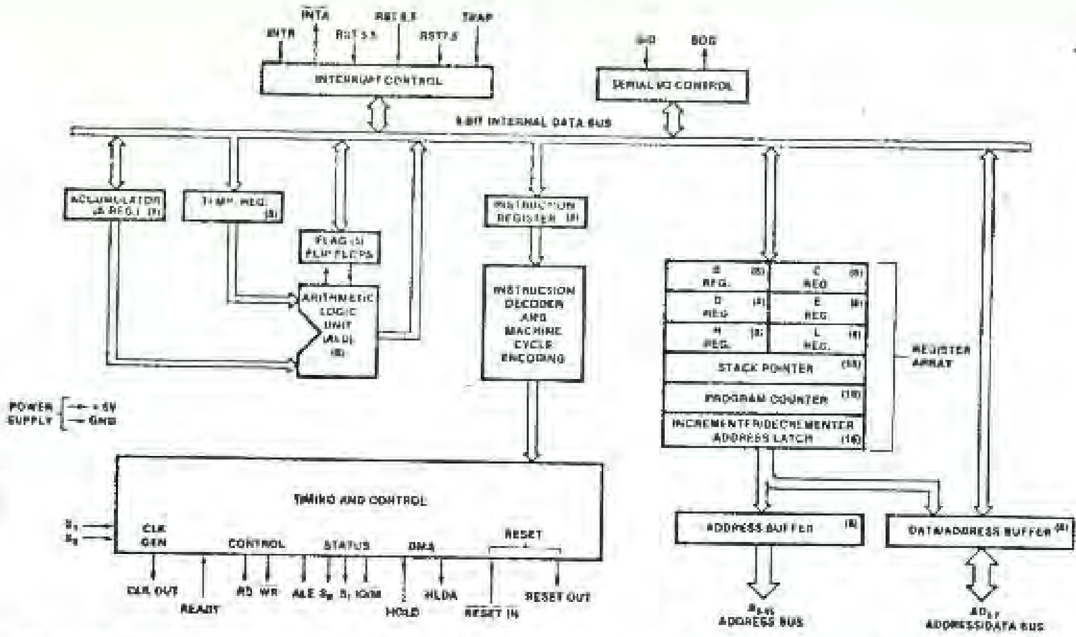


Fig.18 **8085A CPU FUNCTIONAL BLOCK DIAGRAM**, SHOWING REGISTER STRUCTURE

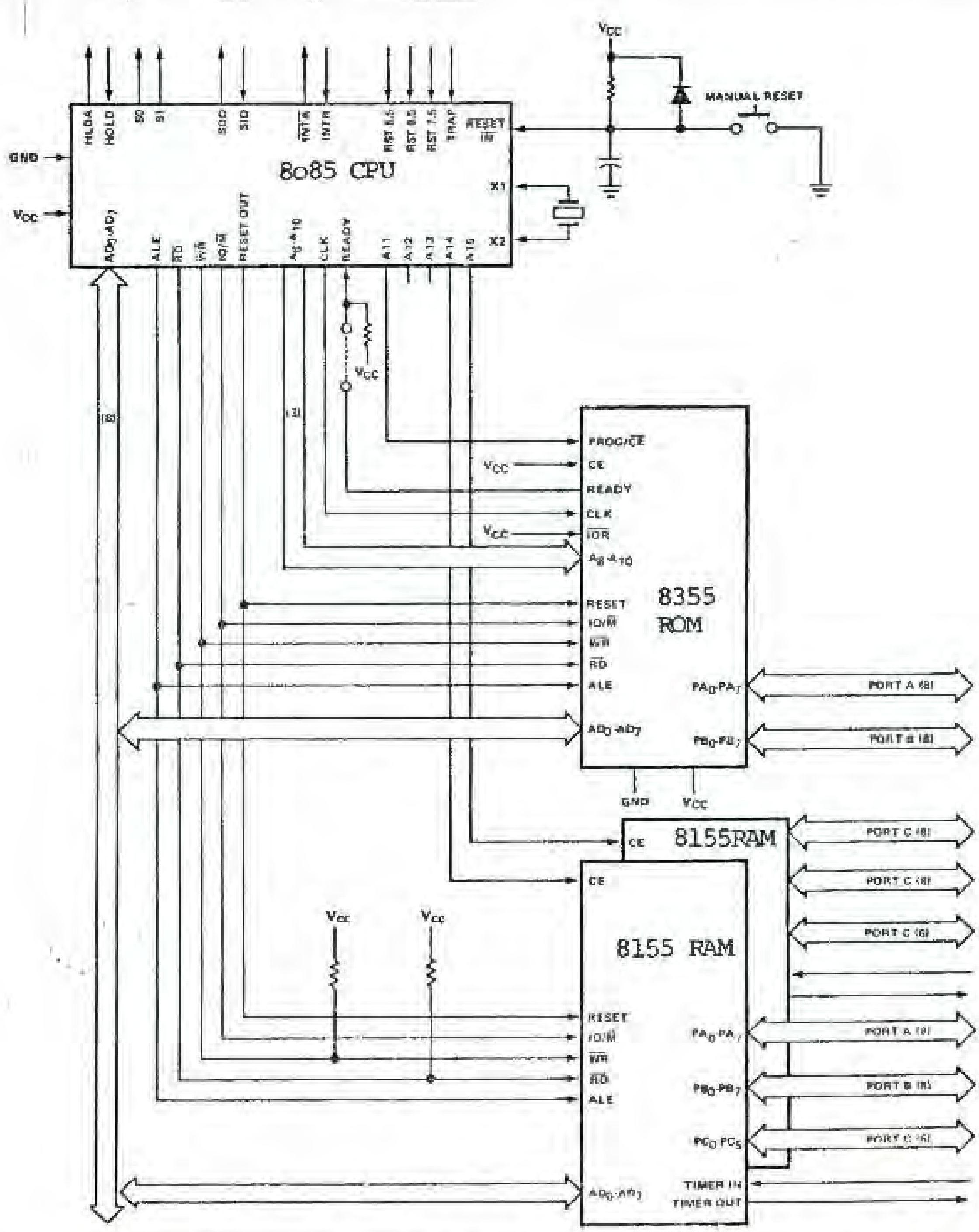


Fig.19 Processor Configuration as used in the current Project

These requirements lead to the Flow Chart shown in Fig. 20. The section between box 0 and box 3 is essentially a 60 s timing loop which is traversed 60 times. Within the loop the water and temperature conditions are checked once a minute to ensure that they persist. Alternatively, we can set the delay, box 2, to 30 s, say, and traverse the loop 120 times. Please refer to section 3.3.3 for detailed delay analysis.

Similarly, the section between boxes 4 and 5 is a 2 hour delay loop during which the water condition is tested every minute. Thus, at the end of a 3 hour period, with temperature and water in the correct range, an Alarm, box 6, will go off. Temperature and water are checked against references deposited in the DATA section of the programme, locations 2000 h to 2024 h. How these references are obtained and loaded is set out in section 4.2

The entire Flow Chart translates into the Programme Listing between memory locations 2000 h and 28D5 h, as given in Appendix A. Both Assembly and Machine Code with comments are given. The memory capacity of the original SDK 85 Microcomputer is 256 bytes of which only 195 are useable, the rest being reserved as "Scratch Pad" for the Monitor. To store the above programme, memory capacity had to be augmented by an additional RAM memory chip, 8156, this is also shown in Fig. 19.

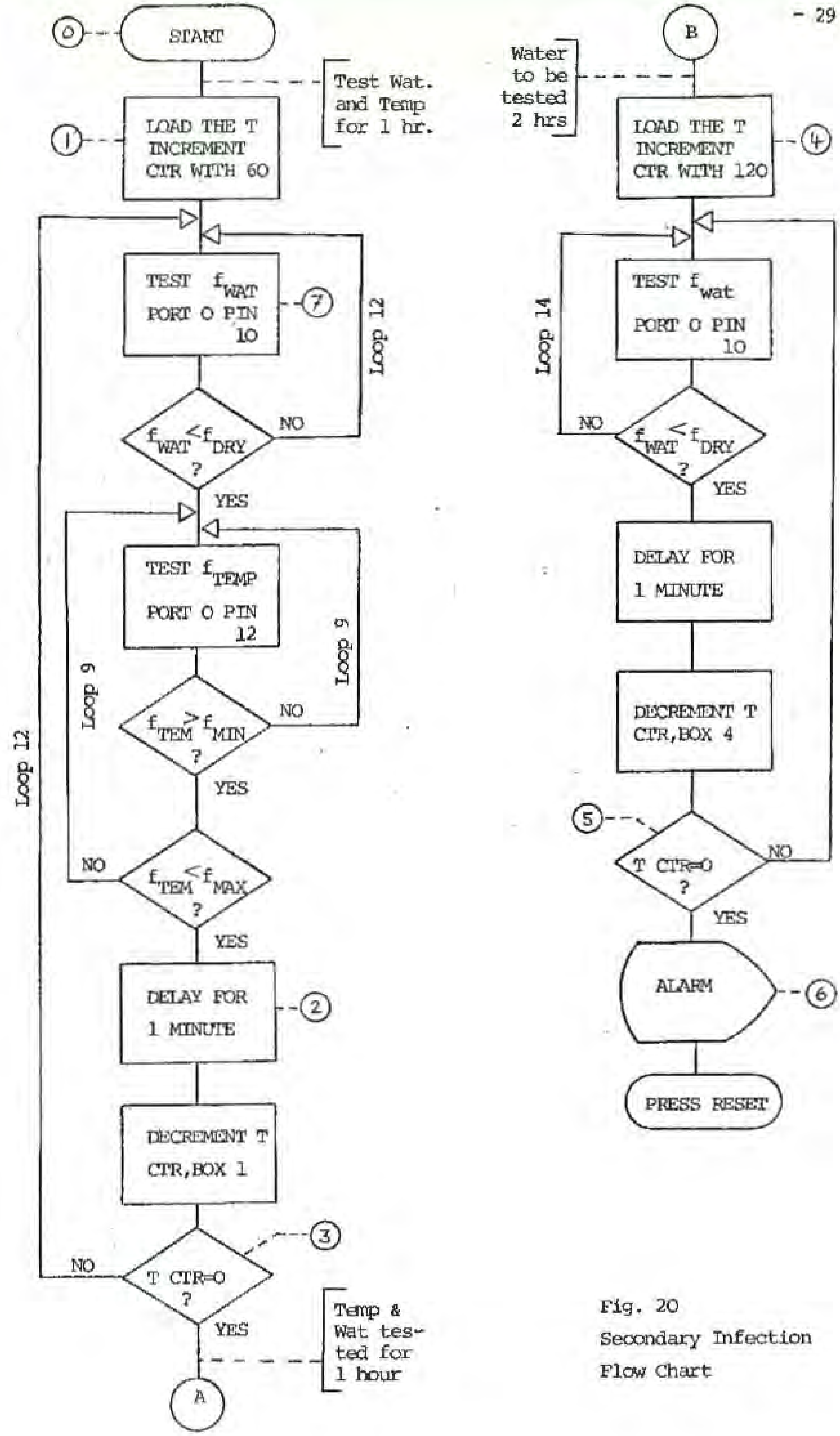


Fig. 20
Secondary Infection
Flow Chart

3.3.2 The Primary Infection Programme

The task: trigger an Alarm when

Free Water available for 2 days

and simultaneously Temperature $\geq 10^{o}C$

These requirements are reflected in the Flow Chart of Fig. 21. It is obvious that we can re-use the previous Flow Chart between boxes 0 and 3, with small changes: The lower temperature reference, box 7, is changed to $10^{o}C$, the upper limit, box 8, is raised arbitrarily high, say $100^{o}C$, so that the answer to box 8 is always "Yes". The time increments between tests, box 9, can remain the same, i.e. 1 minute.

This Flow Chart translates into the Programme Listing between memory locations 2000h and 2853h, as given in Appendix A.

Without wanting to give justification for each single programme instruction it is none the less now neces= sary to look at some important features in detail.

3.3.3 Analysis of the Timing Loop

Actually Fig. 20 is but a Macro Flow Chart and most of the boxes have their own internal life: that of box 2, "Delay for a time T" is shown in Fig. 22. This Flow Chart translates into the programme segment from location 282Bh to 283Ch. The necessary instructions are

LXI = Load Register

DCX = Decrement Register

MOV = Move Data

ORA = Logic OR of Register with accumulator

JNZ = Jump if accumulator not Zero

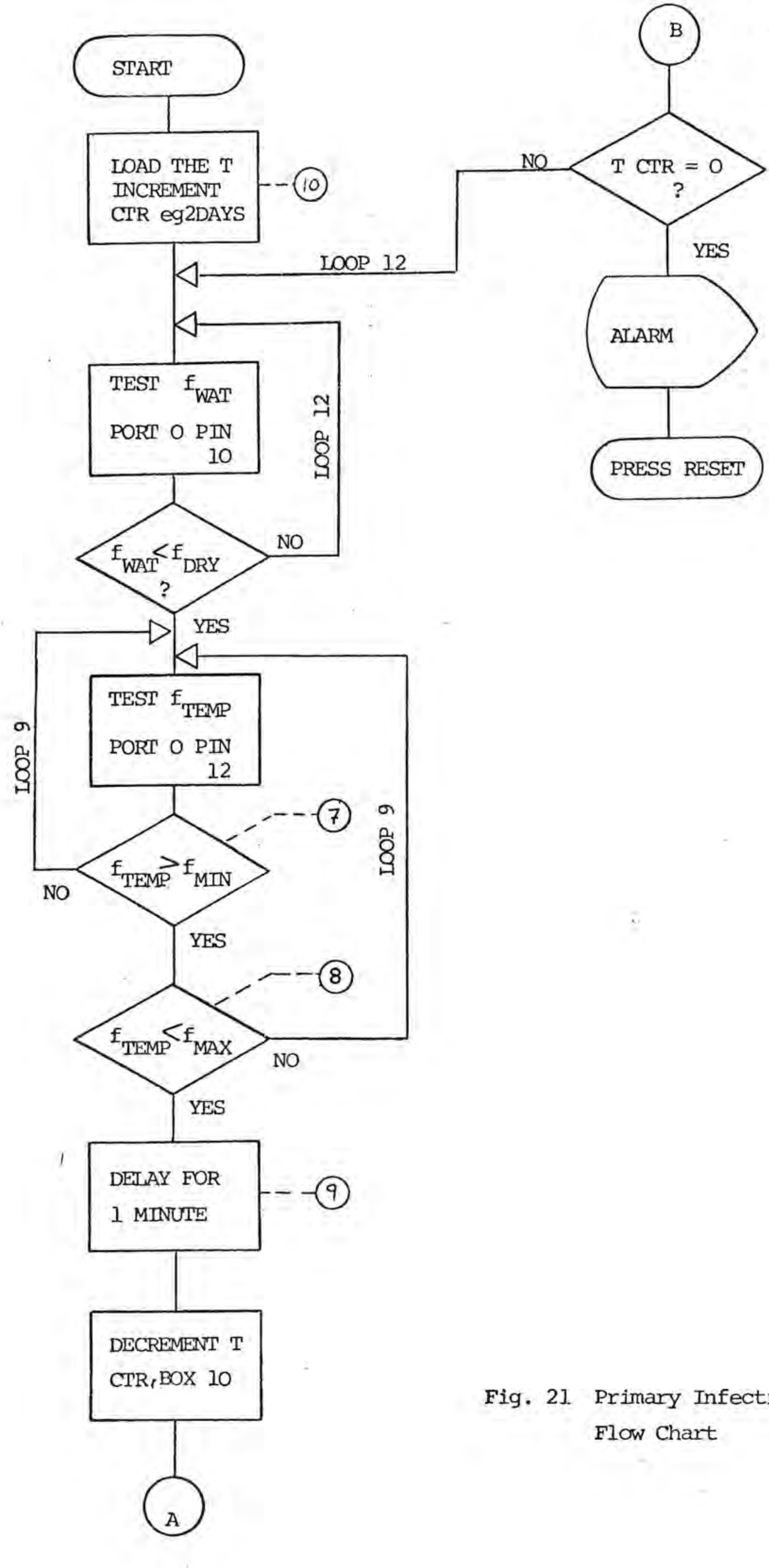


Fig. 21 Primary Infection Flow Chart

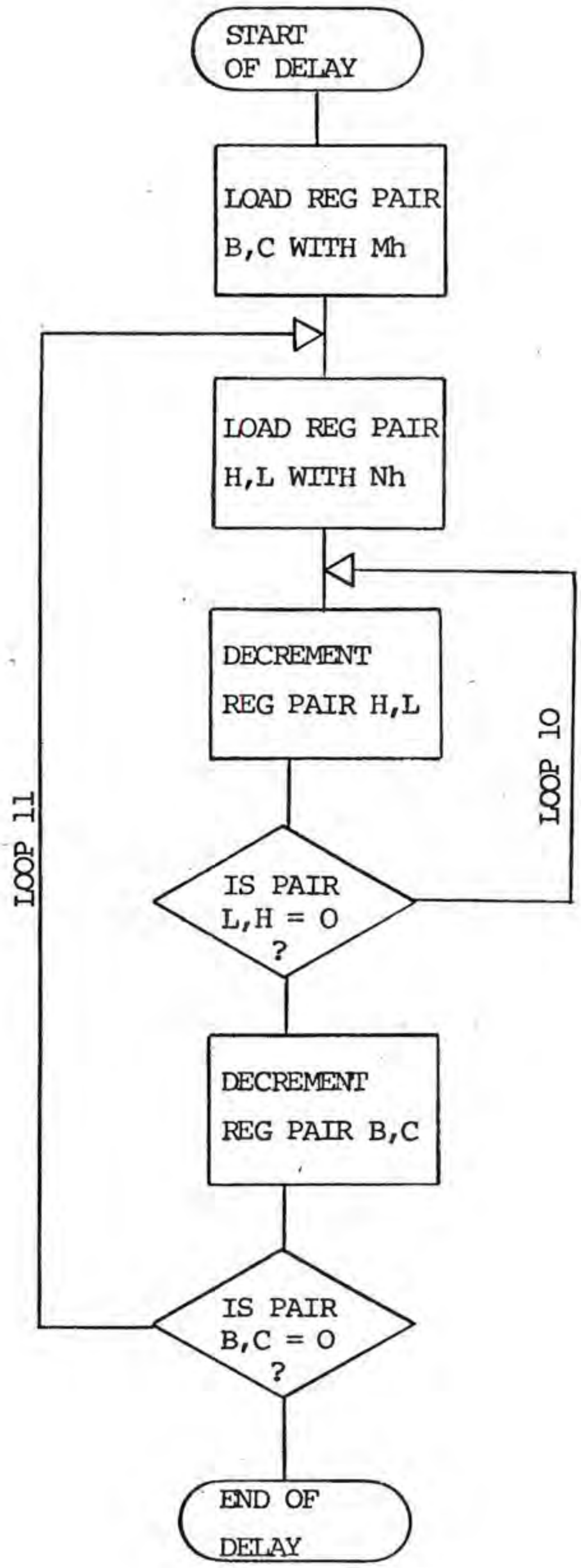


Fig. 22 The Flow Chart for the Time Delay T
Mh and Nh are Hexadecimal Numbers
so chosen that T equals 1 Minute

The execution time T for this segment is

```
    LXI      LXI      DCX  MOV  ORA  JNZ     JNZ  DCX
T = 10t + M(10t + N(6t + 4t + 4t + 10t) + 7t + 6t +

    MOV  ORA  JNZ    JNZ
    4t + 4t + 10t) + 7t
```

The inner bracket in this equation corresponds to Pro= gramme Loop 10, the outer bracket corresponds to Loop 11, please refer Fig.22

The constants 10, 6, 4, 7 in this equation give the number of clock cycles required per instruction indi= cated above the equation,

$t = 325,52ns$ is the duration of one clock cycle. Thus

$T = t(M(24N + 41) + 17)$ (4)

The inner Loop alone (Loop 10) would give a maximum delay of $(24 \times FFFFh + 41)t$

$= (24 \times 65535d + 41)\ 325,52ns$

$= 0,51s$

which is too little for our purpose. The maximum delay obtained from (4) is however

$T_{MAX} = 325,52ns(FFFFh(24FFFFh + 41) + 17)$

$= 9,32$ hours

which is still insufficient for Primary Infection (2 to 3 days). But if we consider that delay T merely is an increment which can be repeated up to FFFFh = 65535d times by looping back from box 3 to box 7 (refer Flow Chart Fig. 20) then the maximum available delay is

9,32 hours x 65535 = 70,7 years.

This will more than cover the eventualities of the current project.

Thus we have, in effect, three nested timing loops, all 16 bits = 65535 steps wide.

Yet, it is amazing how, with only a few locations of memory, split second precision delays of the order of years are obtained from a machine clocking at 325ns! This kind of flexibility allows us to chose the test interval anywhere between a fraction of a second and hours. It appears to be both reasonable and convinient to choose 1 minute as test interval for Primary as well as Secondary Infection, i.e. Water and Temperature conditions are tested once a minute. Thus the number deposited in the T increment counter directly gives the total duration of the Primary and Secondary detection cycle in minutes.

How do we select the parameters M,N of equation (4)?

The test interval is

T = 60s. Let initially

N = FFFFh = 65535d. Now, from (4)

$$M = \frac{(T/t) - 17}{24N + 41} \qquad (5)$$

$$= \frac{(60s/325{,}52ns) - 17}{24 \times 65535 + 41} = 117{,}19, \text{ say } 117d = 75h$$

These figures are entered into the Secondary Infection programme and tested for a target period of 1 hour. One might expect times slightly less than one hour since we rounded M down from 117,19 to 117. The actual times measured were 1 hour + 14 seconds for the programme section box 0 to box 3 and 1 hour - 7 seconds from box 4 to box 6. The increase in the first section occurs because the other programme activities in the loop (Water and Temperature test) more than compensate for the decrease.

The decrease in the second section occurs because programme activities are reduced (no Temperature measurement), thus the reduction of M prevails.

It is possible to account for these deviations to a high degree of accuracy by meticulously counting the cycle times of all programme instructions outside the timing loops.

However, a more analogue approach seems entirely adequate for the biological experiment at hand:

14s per 60T increments is equivalent to 0,23s per T increment. Let us use parameter N of the inner loop for "fine tuning". With

T = 60,0s - 0,23s = 59,77s and

M = 117, we obtain from (4)

$$N = (1/24M)(T/t + 17) - 41 \qquad (6)$$

$$= (1/24 \times 117)((59{,}77s/325{,}52ns) - 17) - 41$$

$$= 65349d = FF45h$$

subsequently, FF40h gave the most accurate practical results. Similarly, for the second part, we raise M to 118d = 76h and then we fine tune N to FFFDh.

To summarise:

Referring to Fig. 20, for the first programme section (box 0 to 3) load

75h into location 282Ch

40h into location 282Fh

FF into location 2830h

for the second programme section (box 4 to 6) load

76h into location 28B4h

FDh into location 28B7h

FFh into location 28B8h

With these figures the 1 hour testrun gave 1 hour ± 0 seconds and 1 hour - 3 seconds, respectivelly.

3.3.4 Measuring the Periodic Time of the Water and Temperature Oscillators

This operation is depicted by the Flow Chart of Fig. 23 which represents in fact the interior of box 7 of the Macro Flow Chart of Fig. 20. The method used is to increment a register pair (B,C) for as long as the oscillator output is in the HI state, and this condition is tested with a JNZ (jump not zero) instruction. Then, when the pulse goes to the LO state, the same register pair is incremented for as long as the pulse is in the LO state, this condition is tested by the instruction JZ (jump zero).

Let this process be repeated for Y cycles, eg.
Y = 255d = FFh (set by contents of register L, instruction at address 2037h in Programme Listing, Appendix A). Let X = accumulated count in register pair B,C then we have

<u>for the HI state</u>

Instruction	Clock cycles	
INO input from port 0	10	= 33 happens X/2 times
ANI logical AND	7	
INXB increment B,C	6	
JNZ jump not zero	10	
JNZ	7	happens Y times

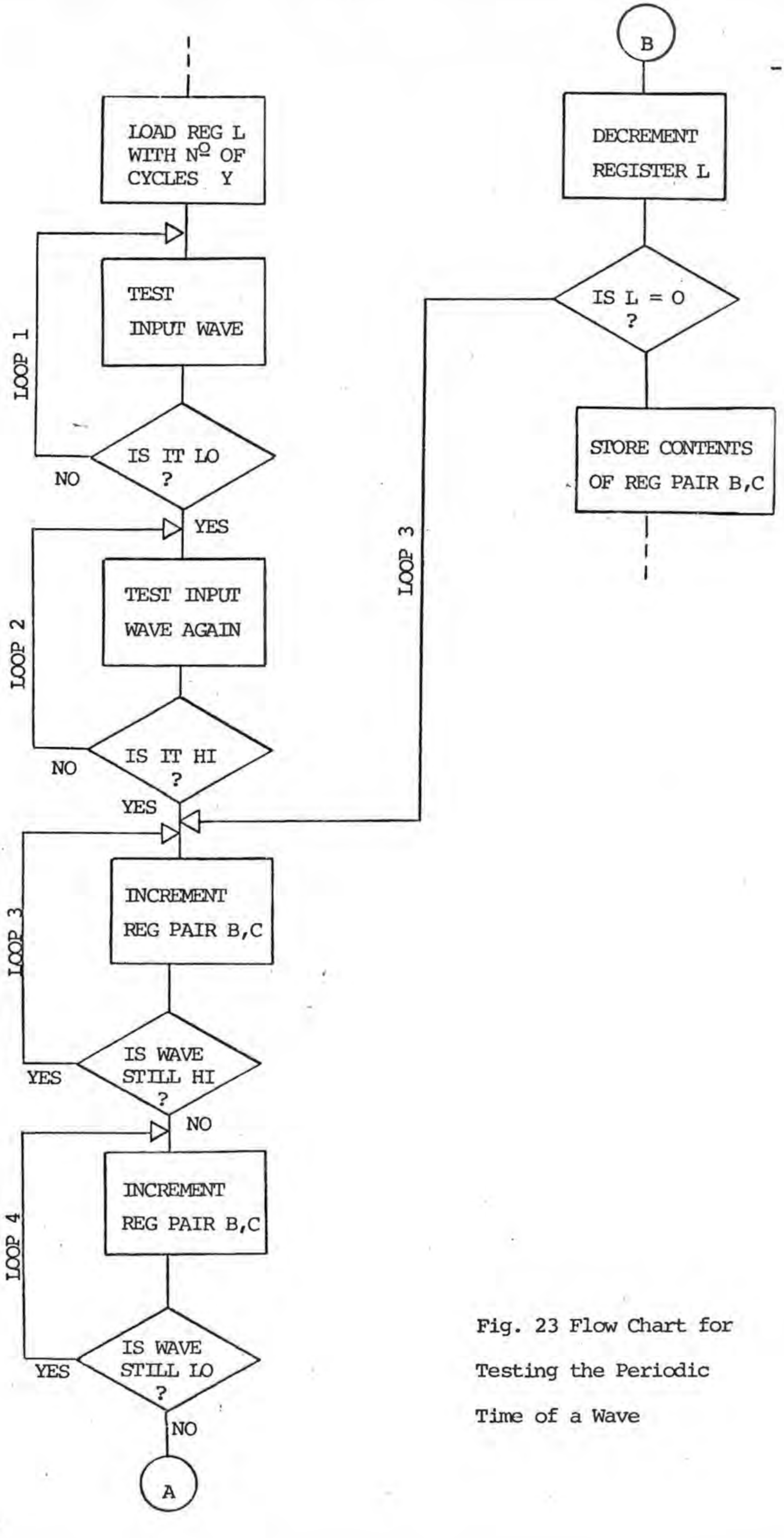


Fig. 23 Flow Chart for Testing the Periodic Time of a Wave

and <u>for the LO state</u>

Instruction	Clock cycles	
INO input from port 0	10	= 33 happens X/2 times
ANI logical AND	7	
INXB increment B,C	6	
JZ jump zero	10	
JZ	7	happens Y times
DCRL decrement reg L	4	= 14 happens (Y - 1) times
JNZ jump not zero	10	
JNZ	7	happens once

Thus the total time measured is

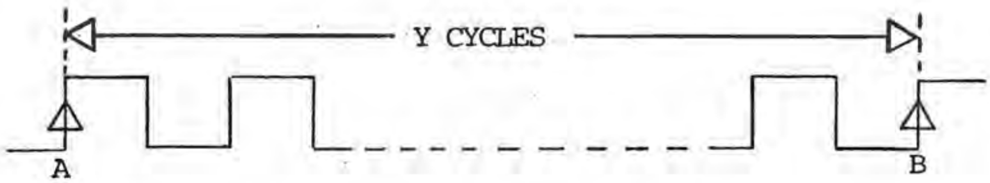
$(X/2)33t + 7Yt + (N/2)33t + 14(Y - 1)t + 7Yt + 7t$

$= t(33X + 14Y + 14(Y - 1) + 7) = t(33X + 28Y - 7)$

= Y x Periodic Time

Two uncertainties must be added to this total time:

(i) Uncertainty in sensing the first rising edge of the Y cycles:



At best the "JZ Loop 2" instruction (refer Programme Listing, address 2047, Appendix A) becomes untrue precisely at A. At worst this instruction is still executed at A, in which case the fact that the pulse is HI will be sensed 8,789 μs too late:

INO	10	27 x 325,52ns = 8,789 μs
ANI	7	
JZ	10	

Since we don't know whether this uncertainty has occured or not, the start of the count into register pair B,C (Loop 3 and Loop 4) is uncertain by $\pm$ 8,789μs

(ii) Uncertainty in sensing the last rising edge. At worst the pulse level will be sensed as LO at B - hence another increment will be added to the register pair B,C - but the pulse will in fact rise HI immediately afterwards, in which case the last increment should not have been added to pair B,C.
The duration of this last increment is

$$\left.\begin{array}{lr} \text{INO} & 10 \\ \text{ANI} & 7 \\ \text{INXB} & 6 \\ \text{JZ} & 7 \end{array}\right\} \; 30 \times 325{,}52\text{ns} = 9{,}765\ \mu\text{s}$$

Again, since we have no means of knowing whether this increment has been added or not the uncertainty is $\pm$ 9,765 μs. Thus total uncertainty
$\pm$ (8,789 + 9,765)μs = $\pm$18,55 μs.
Since these uncertainties occur only on the first and last rising edge their effect on the accuracy of the periodic time measurement is reduced by measuring over as many periods as possible. Thus
Total Time = t(33X + 28Y - 7) $\pm$18,55 μs and

$$\text{Periodic Time} = \frac{t(33X + 28Y - 7) \pm 18{,}55\ \mu\text{s}}{Y} \quad (7), \text{ and}$$

$$X = (1/33)((Y/t)(T \pm 18{,}55\ \text{us}) + 7 - 28Y) \qquad (8)$$

where $t = 325{,}52ns$

X = (decimal) count accumulated in register pair B,C

Y = number of cycles counted, register L

T = Periodic Time of wave

One must remember however, that accuracy of periodic time measurement is not our ultimate goal. Good precision, i.e. repeatability with respect to many significant figures, is more important in our context, since we wish to detect changes, rather than absolute values. A digital system, such as a Microcomputer, is therefore well adapted to our task. Indeed, the problem with respect to precision lies with the Temperature and Water Oscillators. Section 3.5 gives more detail on this issue.

We must now establish the lowest allowable oscillator frequency, for if the periodic time becomes too large the count register will overflow. From equation (7) we obtain the maximum alowable periodic time if

$Y = Y_{MAX} = 255$ and

$X = X_{MAX} = FFFFh = 65535d$,

$$\text{Periodic Time}_{MAX} = \frac{325{,}52ns(33x65535 + 28x255 - 7) + 18{,}55\mu s}{255}$$

$$= 2769{,}9\ \mu s$$

Thus the minimum oscillator frequency is 361 Hz. These figures were practically verified as follows:

Frequency	Register Content
363 Hz	FF77
362 Hz	0002

i.e. overflow occured 1 Hz above the calculated value, possibly due to inaccuracy of the frequency counter at hand.

A minimum frequency of 400 Hz can safely be adopted. Although not necessary in our application, this minimum frequency could be further lowered by reducing Y through programme instruction 2038h, with the attending disad= vantage that at high frequencies only a few counts will be accumulated, making the uncertainty of 18,55 us more significant.

3.4 The Prototype - Setup, Methods and Equipment

A picture of the Prototype in operation is shown in Fig. 24.

Fig. 24 The Prototype: Set-up and Equipment during Development Phase

In the centre is the Microcomputer with a keyboard and readout for Data entry and display. To the left of the keyboard the extension RAM and a small sonar transducer (Alarm) can be seen. The large capacitor (50 000 uF) on top of the 5 Volt stabilized power supply was found necessary to saveguard RAM storage against mains tran= sients. The digital Voltmeter closely monitors the supply voltage (5V $\pm$ 0,25V). The two Signal Generators to the left of the meter were used in the early phases of the project to simulate the Water and Temperature Oscillators. These oscillators can now be seen on the IC breadboard below, including the Water Sensor. Their output is monitored by the two Oscillascopes and a Frequency Counter. On the white sheet to the left we discern the Thermistor probe and a Laboratory-type Alcohol Thermometer.

Numerous tests were run with this system and, eventually, it performed to specifications, with all possible com= binations of water and temperature conditions.

A 7°C reference point was established by adding ice cubes to a beaker of stirred water. Thermometer and Thermistor Probe were kept in close proximity. With a similar procedure, but adding hot water into the beaker, the 29°C reference point was established.

Ordinary tap water was used on the Water Sensor, and this posed a problem after a while: Minute barely visible sediments left behind raised the capacitance to a point where "Dry Alarm" was given. Wiping the sensor immediately cleared the problem. Alternatively, the threshold can be somewhat raised by increasing the reference number in the Data section of the programme. The disadvantage of the latter approach is that very fine droplets on a clean sensor might then be ignored.

3.5 Temperature and Supply Voltage Dependance

It has already been stated that repeatability is a major criterion for the success of our project. The Microcomputer is crystal-controlled and poses no problem. The problem lies with the stability of the Temperature and Water Oscillators, e.g. if

$f_{7^oC} = 555$ Hz

$f_{29^oC} = 1288$ Hz

$f_{Dry} = 5500$ Hz

Then we must be able to return to these frequencies to the closest degree of proximity whenever such temperature or water conditions are re-established, independant of time, supply voltage and oscillator temperature. The effect of supply voltage changes on frequency is depicted in Fig. 25. We see that within the allowed supply voltage range (4,75 V to 5,25 V) the frequency deviations are just under 0,5%.

If we differentiate equation (7) we obtain the resultant change in the count register,

$$dX = \frac{dTY}{33t}$$

For 0,5% deviation from the target frequency (5500 Hz) this amounts to

$$dX = \frac{((1/0{,}995 \times 5500\text{ Hz}) - (1/5500\text{ Hz}))256}{33 \times 325{,}52\text{ ns}} = 22$$

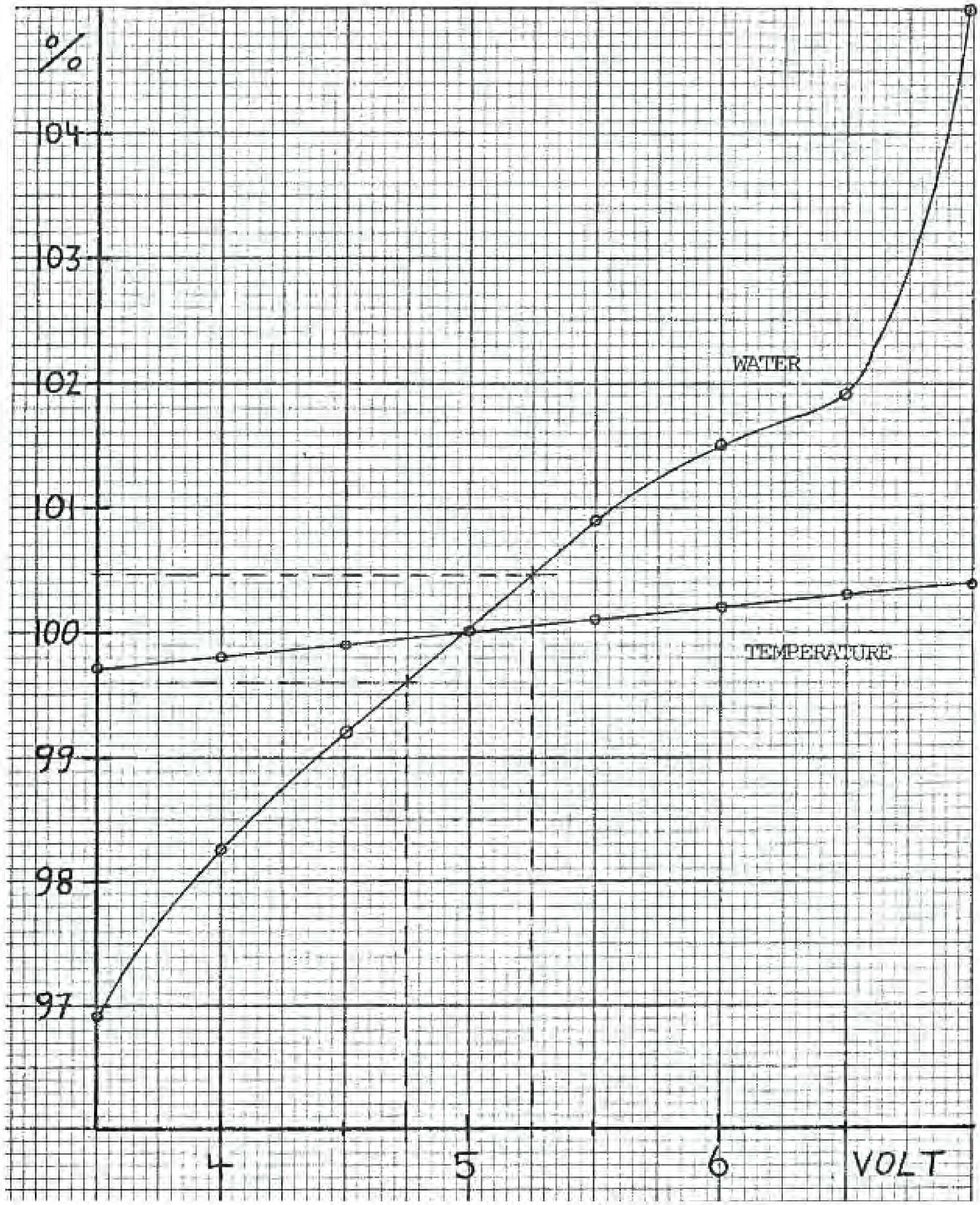


Fig. 25 Effect of Supply Voltage Variations on Oscillator Stability.
The Frequencies of the Water and Temperature Oscillators have been normalized w.r.t. the Power Supply Design Value (5 VOLT). The Tolerance Band centered at 5 VOLTS shows the allowed Supply Voltage Fluctuations based on the 8085 Supply of 5 VOLT ± 5% (4,75 to 5,25 VOLT). Associated worst case Frequency Changes are + o,45% and - o,4%.

i.e. the number stored as Water Reference in the Microcomputer must be increased by 22 to avoid a "Dry Sensor Alarm" at the upper limit of supply voltage. The corresponding figure for the Temperature Oscillator is a count of 3.

Interestingly, the manufacture states a "typical" voltage sensitivity of 0,1% per volt, whereas the measured values are 0,16% (Temperature Oscillator) and 1,7% (Water Oscillator).

With regard to temperature stability the Data Sheet for the 556 Timer gives 150 ppM/degree as typical. This amounts for the Water Oscillator to

$5500\ Hz \times 150 \times 10^{-6}$/degree = 0,8 Hz/degree, and for the Temperature Oscillator, at 25^{o}C,

$1192\ Hz \times 150 \times 10^{-6}$/degree = 0,2 Hz/degree.

These suprisingly good figures were supported by the following experiment: The oscillators were enclosed into a box and the temperature inside the box was raised from 20^{o}C to 50^{o}C by means of a hair dryer. No measurable frequency drift was experienced!

4. USING THE MILDEW DETECTOR - A PRACTICAL VIEWPOINT

The prospective user of this instrument will rarely concern himself with the details of programming etc. He sees a - presumably - useful box and wishes to know how to use it. Let us assume that the system is powered up and that the programme has been loaded, via the keyboard or otherwise. Then three things remain to be done:

Set the system to Primary Infection or to
Secondary Infection

enter Water and Temperature References

enter Timing Information.

All this is done through the keyboard.

4.1 Primary or Secondary Infection ?

	enter	into location
For Primary Infection		
	00	2844
	00	2845
	00	2846
For Secondary Infection	C3	2844
	6C	2845
	28	2846

For example, for Secondary Infection the following sequence of buttons on the keypad have to be depressed for the Enter Procedure:

RESET, SUBST MEM, 2844, NEXT, C3, NEXT, 6C, NEXT, 28, NEXT, RESET.

4.2 How to obtain Water and Temperature References

These are required irrespective of Primary or Secondary Infection.

Set the programme to Primary Infection, as indicated in 4.1 above.

(i) Water Reference

enter	into location
00	2003
00	2004

Ensure Water Sensor is absolutely dry.

Press RESET
GO
2025
EXEC

After approximately 1 second press

RESET
SUBST MEM
2001
NEXT

The two right hand characters on the display are the LO byte, e.g. 7D

Press NEXT,

the displayed location is now 2002, the two right hand characters are the HI byte, e.g. 08

Thus water reference 087D.

However, if we load this number as reference the ALARM will trip even if the Sensor is dry, because mathe= matically we are on the dry/wet boundry. We circumvent this problem by giving the reference a value slightly "dryer than dry" and thereby creating a small "guard band". A beneficial side effect of the guard band is that small variations in oscillator frequency (see section 3.5) do not course a false Alarm. Incrementing the third most significiant digit by one gives very satisfactory operation without undue desensitization (a finger held 1 cm above the sensor will still trip the Alarm). It is interesting to note that, given a very stable Oscillator one can by means of the desensitising guard band set the Alarm threshold anywhere between mist and large drops of water.

Thus, in our example the reference to be used is 088D.

Enter this water reference via the keypad:

	enter	into location
LO byte	8D	2003
HI byte	08	2004

(The enter procedure was described in section 4.1 above).

Note that anything displayed on the readout or entered via the keyboard is in hexadecimal notation rather than the more familiar decimal notation.

All we need to know at this stage is that hexadecimal numbers can contain the letters A to F in addition to the digits 0 to 9, our water reference 088D is an example.

Letters are incremented just like numbers e.g. a water reference of 4BCA would become 4BDA. Except for F, which is incremented to 0 with a carry of 1, e.g.

12F4 becomes 1304, or

ABFD becomes ACOD.

(ii) Temperature Reference

a) Low Reference Point, e.g. 7°C

enter	into location
00	2009
00	200A

Cool the temperature sensor to 7°C

Press RESET
GO
2080
EXEC

After approximately 1 second press

RESET
SUBST MEM
2005
NEXT

The two right hand characters on the display are the LO byte, e.g. 5D

Press NEXT,

the displayed location is now 2006, the two right hand characters are the HI byte e.g. 9E.

Thus 7°C reference 9E5D.

b) <u>High Reference Point, e.g. 29°C</u>

(For Secondary Infection only)

Raise temperature of sensor to 29°C.

Repeat procedure a) above.

Thus 29°C reference, e.g., 45D8

Now enter the temperature references for Secondary Infection via the keyboard:

	enter	into location	
LO byte	5D	2009	Low ref.
HI byte	9E	200A	e.g. 7°C
LO byte	D8	200B	High ref.
HI byte	45	200C	e.g. 29°C

(The enter procedure was described in section 4.1)

Note that for Primary Infection no High Reference Point is required and procedure b) falls away.

The Low Reference Point is measured as in a) above, with sensor temperature e.g. 10°C.

Thus for Primary Infection enter as follows:

	enter	into location	
LO byte	as measured	2009	low ref. e.g.
HI byte	as measured	200A	10°C procedure a)
LO byte	00	200B	
HI byte	00	200C	

4.3 How to set the Timing

(i) Primary Infection

Only one delay time in minutes need be entered.

Example: required delay = 2½ days = 3600 minutes

Convert this decimal number into hexadecimal notation (see Appendix B for procedure)

Thus 3600 d = OE1Oh

Enter this number through the keypad.

	enter	into location
LO byte	10	2010
HI byte	OE	2011

(Note: Range is from 0001h to FFFFh = 1 minute to 45½ days, extendable to 70 years, refer section 3.3.3)

(ii) Secondary Infection

Two time delays in minutes must be entered.

Example:

Temperature (7°C - 29°C) for 1 hour, and

Free Water for 3 hours

The first delay is 1h = 60 minutes

60d = 003Ch

	enter	into location
LO byte	3C	2010
HI byte	00	2011

The second delay is 3 hours - 1 hour = 2 hours

= 120 minutes

120d = 78h

	enter	into location
LO byte	78	2020
HI byte	00	2021

4.4 Running the System

After having loaded Water, Temperature and Time Refe= rences the system is ready!

Press RESET
GO
2025 (irrespective of Primary or Secondary Infection, see section 4.1)
EXEC

To cancel a test run or the Alarm press RESET.

During the familiarisation stage it can be a nuisance having to wait out delays, even as short as one minute.

Remedy:

enter	into location
01	2010
00	2011
01	2020
00	2021
01	282C
01	28B4

Now the system will respond within 1 second with an Alarm, provided Water and Temperature conditions are met i.e. the procedures of sections 4.1 and 4.2 must have been followed.

Important: To return to normal operation restore as follows:

enter	into location
75	282C
76	28B4

5. CONCLUSION AND RECOMMENDATIONS

The Electronic Monitor/Alarm System does what we set out to achieve but will have to prove its worth in field tests. One or two Mildew Detectors should be placed into the vineyard in positions of worst case micro-climate.

For this purpose the equipment should be portable and battery supported. Under these circumstances a CMOS Micro-computer having low power consumption and wide supply voltage range would be more suitable. For example, National's NSC 800 Micro-computer consumes less than 0,1 W (8085 2,5 W), operates on 3 to 12 Volt (8085 4,75 to 5,25 Volt) and is 8085 Software compatible! Almost the entire programme would be stored into non-volotile Programmable Read-Only-Memory (PROM), except for the DATA Section which must remain in keyboard accessible Random Access Storage (RAM) so that Water, Temperature and Time References can be entered as required.

There is also scope for refinement of the Water Sensor: to make this device a perfect leaf-wetness detector - our ultimate goal - surface roughness and specific heat capacity would have to be matched to that of a living leaf.

It is nonetheless hoped that the Mildew Detector presented here will help the cause against the disease.

References

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2) Matthee F N, Heyns A J, "Donsskimmel (Plasmopara Viticola)", Herdruk uit "Die Sagtevrugteboer" Deel 9, Jaargang 19 (September 1969)

3) "Wingerd-Donsskimmel in Wes-Kaapland", Handelinge van 'n simposium aangebied deur Die Suid-Afrikaanse Vereniging vir Plantesiektekunde en Mikrobiologie en die Universiteit van Stellenbosch, Stellenbosch 25 Augustus 1977

4) "Die Sagtevrugteboer", Augustus 1970, Jaargang 20, Deel 8

5) Priestley J H, "An Introduction to Botany", Longmans, London (1968), p 512

6) INTEL Corporation, "MSS-85 User Manual", September 1978

7) INTEL Corporation, "SDK 85 System Design Kit User's Manuel", 1978

8) INTEL Corporation, "Assembly Language Programming Manuel", 1978

Appendix - A   8085 Assemly and Machine Code Programme Listing

ADDRESS	MNEMONIC INSTR.	MACHINE OP CODE	DATA & COMMENT	
			Data Section	
2000				
2001			LO	Measured WAT Time (=Minuend) & Dif.
2002			HI	
2003			LO	Reference WAT Time (=Subtrahend)
2004			HI	
2005			LO	Measured TEMP Time (=Minuend) & Dif.
2006			HI	
2007			LO	Copy of Temp Time
2008			HI	
2009			LO	Reference 7° TEMP Time (=Subtrahend)
200A			HI	
200B			LO	Reference 29° TEMP Time (=Subtrahend)
200C			HI	
200F	LX1D	11		
2010			LO	MINUTE CTR. WAT, TEMP PRIM/SEC INF
2011			HI	
2012	JMP	C3		
2013		36		
2014		20		
201F	LX1D	11		
2020			LO	WAT. MINUTE CTR. SEC. INF.
2021			HI	
2022	JMP	C3		
2023		6D		
2024		28		

Programme Section

	2025	LXISP	31	
	2026		C2	Init stack pointer
	2027		20	
	2028	MVIA, FF	3E	
	2029		FF	Make Port 1 O/P
	202A	OUT3	D3	
	202B		03	
	202C	MVIA, FF	3E	
	202D		OO	Make all pins of Port I
	202E	OUT1	D3	LO
	202F		01	
	2030	SUBA	97	
	2031	OUT2	D3	Make Port 0 I/P
	2032		02	
	2033	JMP	C3	Fetch contents of
	2034		OF	Minute Ctr. from
	2035		20	DATA section
	2036	NOP	00	
L12	2037	MVIL, FF	2E	Load Reg 2 with No of cycles Y
	2038		FF	over which T_{WAT} is to be meas.
	2039	LXIB	01	
	203A		00	CLR Pair B,C; this will
	203B		00	be the T_{WAT} Ctr.
L1	203C	INO	DB	
	203D		00	Test bit 7 (pin 10)
	203E	ANI 80	E6	of Port 0
	203F		80	
	2040	JNZ L1	C2	Wait until bit 7 is LO
	2041		3C	
	2042		20	
L2	2043	INO	DB	
	2044		00	Now that bit 7 is LO
	2045	ANI 80	E6	test it again
	2046		80	
	2047	JZ L2	CA	Wait until bit 7 is HI
	2048		43	
	2049		20	

```
L3 204A    INO        DB
   204B               00      now that bit 7 is HI
   204C    ANI 8D     E6      incr. Pair B,C
   204D               80
   204E    INX B      03
   204F    JNZ L3     C2      Keep incr. Pair B,C as
   2050               4A      long as bit 7 is HI
   2051               20
L4 2052    INO        DB
   2053               00
   2054    ANI 80     E6      Now that bit 7 has gone
   2055               80      LO keep inc. Pair B,C as
   2056    INXB       03      long as bit 7 is LO
   2057    JZ L4      CA
   2058               52
   2059               20
   205A    DCRL       2D      Look at the next cycle
   205B    JNZ L3     C2      HI/LO of the wave.
   205C               4A      Again incr. Pair B,C
   205D               2L      Repeat until Reg 2 = 0
   205E    NOP        00
   205F    MOV A,C    79
   2060    ST A       32      Store Reg C in loc.
   2061               01      2001
   2062               20
   2063    MOV A,B    78
   2064    STA        32      Store Reg B in loc.
   2065               02      2002
   2066               20
   2067    NOP        00      SUBTRACTION WAT
   2068    LXIB       01
   2069               01      Load Pair B,C with Adr.
   206A               20      of Minuend's LO Byte
   206B    LXIH       21
   206C               03      load Pair H,L with Adr.
   206D               20      of Subtrahend's LO Byte
   206E    XRA,A      AF      CLR ACC i.e. the Carry Flag
   206F    LDAX,B     0A      load ACC with cont. of loc.
                              pointed to by B,C
   2070    SBB,M      9E      Subtr. from ACC cont. of
                              loc. adr. by H,L
```

	2071	STAX,B	02	Store ACC in loc. adr. by B,C
	2072	INXB	03	B,C now points to Minuend's HI byte
	2073	INXH	23	H,L now points to Subtrahend' HI byte
	2074	LDAX,B	0A	Subtract HI byte, store
	2075	SBB,M	9E	in loc. adr. by B,C (2002)
	2076	STAX,B	02	
	2077	NOP	00	
	2078		00	
	2079		00	
	207A	JC L12	DA	If dif. is negative
	207B		37	test I/P again
	207C		20	
	207D	NOP	00	
	207E	NOP	00	
	207F	NOP	00	

MEAS. PER TIME TEMP.

L9	2080	MVIL,FF	2E	load Reg L with No of
	2081		FF	cycles over which T_{TEMP} is to be measured
	2082	LXIB	01	
	2083		00	CLR Pair B,C. This will
	2084		00	be the T_{TEMP} Ctr.
L5	2085	INO	DB	Test bit 5 of Port 0
	2086		00	
	2087	ANI 0010 0000	E6	
	2088		20	
	2089	JNZ L5	C2	Wait until bit 5 is LO
	208A		85	
	208B		20	
L6	208C	INO	DB	
	208D		00	Now that bit 5 is LO
	208E	ANI 20	E6	test it again
	208F		20	

```
   2090   JZ L6     CA    
   2091             8C    Wait until bit 5 is HI
   2092             20
L7 2093   INO       DB
   2094             00
   2095   ANI 20    E6    Now that bit 5 is HI
   2096             20    incr. Pair B,C
   2097   INXB      03
   2098   JNZ L7    C2
   2099             93    Keep incr. Pair B,C as
   209A             20    long as bit 5 is HI
L8 209B   INO       DB
   209C             00
   209D   ANI 20    E6    Now that bit 5 has gone
   209E             20    LO keep incr.
   209F   INXB      03    Pair B,C as long as
   20A0   JZ L8     CA    bit 5 is LO
   20A1             9B
   20A2             20
   20A3   DCRL      2D    Look at the next cycle
   20A4   JNZ L7    C2    HI/LO of the wave.
   20A5             93    Again incr. Pair B,C.
   20A6             20    Repeat until Reg L = 0
   20A7   NOP       00
   20A8   MOV A,C   79
   20A9   STA       32    Store Reg C in loc.
   20AA             05    2005
   20AB             20
   20AC   MOV A,B   78
   20AD   STA       32    Store Reg B in loc.
   20AE             06    2006
   20AF             20
   20B0   MOV A,C   79
   20B1   STA       32    Copy Reg C into loc.
   20B2             07    2007
   20B3             20
```

20B4	MOV A,B	78	
20B5	STA	32	Copy Reg B into loc.
20B6		08	2008
20B7		20	
20B8	NOP	00	
20B9	NOP	00	
			<u>SUBTRACTION TEMP.</u>
20BA	JMP	C3	
20BB		00	
20BC		28	
2800	LXIB	01	<u>First test the 7° limit</u>
2801		05	Load Pair B,C with Adr.
2802		20	of Minuend's LO byte
2803	LXIH	21	
2804		09	Load Pair H,L with Adr.
2805		20	of Subtrahend's LO Byte 7°
2806	XRA,A	AF	CLR ACC, i.e. carry Flag!
2807	LDAX,B	OA	Load ACC with cont. of loc. pointed to by B,C
2808	SBB,M	9E	Subtr. from ACC cont. of loc. adr. by H,L
2809	STAX,B	02	Store ACC in loc. adr. by B,C (2005)
280A	INXB	03	B,C now points to Minuend's HI byte
280B	INXH	23	H,L now points to Subtrahend's HI byte 7°
280C	LDAX,B	OA	
280D	SBB,M	9E	Subtract HI byte, store
280E	STAX,B	02	in loc. adr. by B,C (2006)
280F	JZ L9	CA	
2810		80	
2811		20	If dif. is zero or
2812	JN L9	D2	positive test I/P
2813		80	again
2814		20	
2815	NOP	00	<u>Now test the 29° limit</u>

	2816	LXIB	01	Load Pair B,C with
	2817		07	Adr. of copy of
	2818		20	Minuend's LO byte
	2819	LXIH	21	
	281A		0B	Load Paid H,L with Adr.
	281B		20	of Subtrahend's LO byte 29^{o}
	281C	XRA,A	AF	CLR ACC i.e. carry flag
	281D	LDAX,B	OA	Load ACC with Minuend's LO byte
	281E	SBB,M	9E	Subtr. from Minuend's cont. of loc. adr. by H,L
	281F	STAX,B	02	Store dif. in loc. adr. by B,C (2007)
	2820	INXB	03	B,C now points to HI byte of copy of Minuend
	2821	INXH	23	H,L now points to HI byte of Subtrahend
	2822	LDAX,B	OA	Subtr. Hi bytes, store in
	2823	SBB,M	9E	loc. adr. by B,C (2008)
	2824	STAX,B	02	
	2825	JC L9	DA	If negative meas.
	2826		80	TEMP TIME again!
	2827		20	
	2828	NOP	00	
	2829	NOP	00	
	282A	NOP	00	

<u>1 MINUTE DELAY</u>

	282B	LXIB	01	
	282C		75 LO	Load Pair B,C with a
	282D		00 HI	number M
L11	282E	LXIH	21	
	282F		40 LO	Load Pair H,L with a
	2830		FF HI	number N
L10	2831	DCXH	2B	
	2832	MOV A,H	7C	Keep decrementing Pair
	2833	ORA L	B5	H,L until it is zero
	2834	JNZ L10	C2	
	2835		31	
	2836		28	

	2837	DCXB	OB		
	2838	MOV A,B	78		Decrement B,C. If it
	2839	ORA,C	B1		is not zero GO TO 282E
	283A	JNZ L11	C2		and load Pair D,E again
	283B		2E		
	283C		28		
	283D	NOP	00		End of 1 Minute Delay
	283E	DCXD	1B		
	283F	MOVA,D	7A		Decrement Minute Ctr.,
	2840	ORA E	B3		if not zero repeat Wat
	2841	JNZ L12	C2		Temp test
	2842		37		
	2843		20		
	2844	NOP	00	C3	Primary Secondary
	2845	NOP	00	6C	Infection Infection
	2846	NOP	00	28	
					ALARM
L13	2847	MVIA	3E		
	2848		FF		Make pin 2 (bit 7)
	2849	OUT 1	D3		of Port 1 HI
	284A		01		
	284B	LXID	11		
	284C		26		
	284D		00		
L21	284E	DCXD	1B		
	284F	MOVA,D	7A		Delay 0,51 s
	2850	ORA,E	B3		
	2851	JNZ L21	C2		
	2852		4E		
	2853		28		
	2854	MVIA	3E		
	2855		7F		Make pin 2 (bit 7)
	2856	OUT 1	D3		of Port 1 LO
	2857		01		

	2858	LXI	11	
	2859		26	
	285A		00	
L22	285B	DCXD	1B	Delay 0,51 s
	285C	MOVA,D	7A	
	285D	ORA A,E	B3	
	285E	JNZ L22	C2	
	285F		5B	
	2860		28	
	2861	JMP L13	C3	Repeat the HI/LO sequence
	2862		47	on pin 2 of Port 1
	2863		28	
	2864	MVIA	3E	
	2865		FF	Make Port 1 O/P
	2866	OUT 3	D3	
	2867		03	
	2868	MVIA,FF	3E	
	2869		00	
	286A	OUT 1	D3	Make all pins of Port 1 LO
	286B		01	
				SECOND.INFEC: ADDIT. WAT TEST
	286C	LXIH	C3	Load Minute Ctr.
	286D		1F	e.g. FOR 2HR DELAY
	286E		20	
L14	286F	MVIL,FF	2E	Load Reg L with No of
	2870		FF	cycles Y for which T_{WAT} to be measured.
	2871	LXI B	01	
	2872		00	CLR Pair B,C this will
	2873		00	be the T_{WAT} Ctr.
L15	2874	INO	DB	
	2875		00	Test pin 10 (bit 7)
	2876	ANI 80	E6	of Port 0
	2877		80	
	2878	JNZ L15	C2	
	2879		74	Wait until bit 7 is LO
	287A		28	

```
L16 287B   INO       DB
    287C             00    Now that bit 7 is LO
    287D   ANI 80    E6    test it again
    287E             80
    287F   JZ L16    CA
    2880             7B    Wait until bit 7 is HI
    2881             28
L17 2882   INO       DB
    2883             00    Now that bit 7 is HI
    2884   ANI 80    E6    incr. Pair B,C
    2885             80
    2886   INXB      03
    2887   JNZ L17   C2    Keep incr. Pair B,C
    2888             82    as long as bit 7 is HI
    2889             28
L18 288A   INO       DB
    288B             00
    288C   ANI 80    E6
    288D             80    Now that bit 7 has gone
    288E   INXB      03    LO, keep incr. Pair B,C
    288F   JZ L18    CA    as long as bit 7 is LO
    2890             8A
    2891             28
    2892   DCRL      2D
    2893   JNZ L17   C2    Look at the next HI/LO
    2894             82    cycle of the wave.  Again
    2895             28    incr. B,C. Repeat until
                           Reg L = 0
    2896   NOP       00
    2897   MOV A,C   79
    2898   STA       32    Store Reg C in loc.
    2899             01    2001
    289A             20
    289B   MOV A,B   78
    289C   STA       32    Store Reg B in loc.
    289D             02    2002
    289E             20
```

```
     289F   NOP       00      SUBTRACTION WAT.
     28A0   LXIB      01      Load Pair B,C with
     28A1             01      Adr. of Minuend's
     28A2             20      LO byte
     28A3   LXIH      21      Load Pair H,L with
     28A4             03      Adr. of Subtrahend's
     28A5             20      LO byte
     28A6   XRA,A     AF      CLR ACC, i.e. carry Flag
     28A7             OA      Load ACC with cont. of
                              loc. pointed to by B,C
     28A8   SBB,M     9E      Subtr. from ACC cont. of
                              loc. adr. by H,L
     28A9   STAX,B    02      Store ACC in loc. adr.
                              by B,C
     28AA   INXB      03      B,C now points to
                              Minuend's HI byte
     28AB   INX H     23      H,L now points to
                              Subtrahand's HI byte
     28AC   LDA X,B   OA      Subtract HI bytes, store
     28AD   SBB,M     9E      dif. in loc. adr. by
     28AE   STAX B    02      B,C (2002)
     28AF   JC L14    DA
     28B0             6F      If dif. negative,
     28B1             28      test T_WAT again
     28B2   NOP       00      1 MINUTE DELAY
     28B3   LXI B     01
     28B4             76      LO byte (C)   Load Pair B,C
     28B5             00      HI byte (B)   with a number M
L20  28B6   LXI H     H 21                  Load Pair
     28B7             FD      LO byte (L)   H,L with a
     28B8             FF      HI byte (H)   number N
L19  28B9   DCX H     2B
     28BA   MOV A,H   7C      Keep decr. Pair H,L
     28BB   ORA L     B5      until it is zero
     28BC   JNZ L19   C2
     28BD             B9
     28BE             28
```

28BF	DCXB	OB	
28C0	MOV A,B	78	Decr. B,C. If ≠ 0
28C1	ORA,C	B1	Go To 28B6
28C2	JNZ L20	C2	and load D,E again
28C3		B6	
28C4		28	
28C5	NOP	00	END OF 1 MIN. DELAY
28C6	DCXD	1B	
28C7	MOV A,D	7A	
28C8	ORA E	B3	Decr. Minute Ctr.
28C9	JNZ L14	C2	(loc. 2000)
28CA		6F	If not zero, test WAT
28CB		28	again
28CC	NOP	00	
28CD	JMP	C3	TURN ON ALARM
28CE		47	
28CF		28	

Note: Instructions 2864 to 286B are included only for convenience. They allow us to run the programme section "Secondary Infection additional Water Test" independantly with a GO 2864 EXEC command. In a normal programme run for Primary or Secondary Infection these instructions are excluded automatically.

Appendix - B

Decimal to Hexadecimal Conversion

In the decimal system we have ten basic characters, in the hexadecimal system we have sixteen basic characters with the following decimal equivalences:

HEX	DEC
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
A	10
B	11
C	12
D	13
E	14
F	15

A decimal number is converted into hexadecimal notation by successive division by 16, noting down the remainder, least significant digit first.

Example (1)

Convert 100d to hexadecimal

100 / 16 = 6, remainder 4

6 / 16 = 0, remainder 6

Thus 100d = 64h

Example (2)

Convert 992d to hexadecimal

992 / 16 = 62, remainder 0

62 / 16 = 3, remainder 14

3 / 16 = 0, remainder 3

Thus 992d = 3E0h

Example (3)

Convert 44015d to hexadecimal

44015 / 16 = 2750, remainder 15

2750 / 16 = 171, remainder 14

171 / 16 = 10, remainder 11

10 / 16 = 0, remainder 10

Thus 44015d = ABEFh

One can always check results by re-converting to decimal using the following scheme:

$64h = 4 \times 16^0 + 6 \times 16^1 = 4 + 96 = 100d$

$3E0h = 0 \times 16^0 + 14 \times 16^1 + 3 \times 16^2 = 0 + 224 + 768 = 992d$

$ABEFh = 15 \times 16^0 + 14 \times 16^1 + 11 \times 16^2 + 10 \times 10^3$

$= 15 + 224 + 2816 + 40960 = 44015d$

Hexadecimal numbers can be broken up into groups of 2 characters called "bytes".

Thus in example (3)

EF is the low order byte, or LO byte, for short

AB is the high order byte, or HI byte.

In example (2)

EO LO byte

03 HI byte

In example (1)

64 LO byte

00 HI byte.

* * *