607604

FORM 1   SPRUSON & FERGUSON

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

APPLICATION FOR A STANDARD PATENT

Aquametrics, Inc., of 5060 Convoy Street, San Diego, California, 92111, UNITED STATES OF AMERICA, hereby apply for the grant of a standard patent for an invention entitled:

        Soil Moisture Monitor

which is described in the accompanying complete specification.

The address for service is:-

        Spruson & Ferguson
        Patent Attorneys
        Level 33 St Martins Tower
        31 Market Street
        Sydney New South Wales Australia

        DATED this EIGHTEENTH day of APRIL 1989

        Aquametrics, Inc.

    By:

                    Registered Patent Attorney

.... TO: THE COMMISSIONER OF PATENTS
             OUR REF: 93220
             S&F CODE: 61000

                    APPLICATION ACCEPTED AND AMENDMENTS

                    RECEIVED ....11 - 12 - 90..................

REPRINT OF RECEIPT
S006871   19/04/89

    5845/2

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

DECLARATION IN SUPPORT OF AN
APPLICATION FOR A PATENT

In support of the application made by Aquametrics, Inc., for a patent for an

invention entitled:

Soil Moisture Monitor

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│      27 NOV 1990         │
│                          │
│       SYDNEY             │
└─────────────────────────┘
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I, ...KENNETH M. CLARE..
               [full name of declarant(s)]
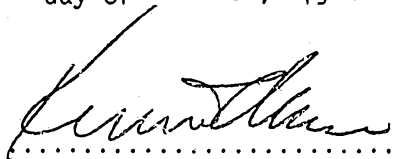
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   ...SAN DIEGO,...CA 92126-4365...

   ....

do solemnly and sincerely declare as follows:

1.   I am authorised by Aquametrics, Inc., the applicant for the patent to
     make this declaration on its behalf.

2.   Richard L. Bireley, of San Diego, California, United States of America,
     is the actual inventor of the invention and the facts upon which the
     applicant is entitled to make the application are as follows:-

     The applicant is the assignee of the invention from the actual inventor.

        DECLARED at San Diego,   this $\mathscr{30}^{th}$ day of October, 1990

                            ....
                                 Signature of Declarant(s)
                            KENNETH M. CLARE
                            President

TO: THE COMMISSIONER OF PATENTS
      AUSTRALIA

STA/2529T

(57) Claim

1.   A device adapted to determine the concentration of water in the earth, comprising:

first and second thin conductive layers having a planar configuration and disposed in adjacent relationship to define first plates of first and second capacitances,

a dielectric material covering the first and second thin conductive layers and defining the dielectric in the first and second capacitances,

the moisture in the earth defining the second plates of the first and second capacitances and defining the connections between the second plates in the first capacitances and the second plates in the second capacitances, and

means for introducing an energizing potential between the first and second thin conductive layers.

607604

S & F Ref: 93220

FORM 10

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

COMPLETE SPECIFICATION

(ORIGINAL)

FOR OFFICE USE:

Class   Int Class

Complete Specification Lodged:
Accepted:
Published:

Priority:

Related Art:

Name and Address
of Applicant: Aquametrics, Inc.
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Complete Specification for the invention entitled:

Soil Moisture Monitor

The following statement is a full description of this invention, including the best method of performing it known to me/us

5845/3

SOIL MOISTURE MONITOR

~~CROSS-REFERENCE TO RELATED APPLICATIONS~~

This application is a Continuation-In-Part of my Application Serial No. 836,217 filed February 28, 1986, which was a Continuation-In-Part of Application Serial No. 688,255 filed January 2, 1985.

FIELD OF THE INVENTION

This invention relates to electronic fluid and moisture level monitors, or sensors for detecting the moisture level in a given medium such as soil. Such sensors are typically used in control of irrigation or watering equipment.

BACKGROUND OF THE INVENTION

Apparatuses for detecting and measuring the presence and level of fluid in a given medium are commonly used for monitoring and controlling fluid levels, flow, relative moisture contents, liquid spills, contamination and the like.

Contemporary sensor technology depends on changes in the dielectric property of the medium caused by variances in fluid level or fluid concentration within the medium. Sensors of contemporary design typically utilize a parallel plate capacitor immersed or embedded in the medium so that a portion of the medium may function as a dielectric between the plates. The capacitor is part of the RC circuit of an oscillator whose frequency varies with changes in the dielectric property of that portion of the medium between the plates. This technique is generally satisfactory when the dielectric-forming medium is a fluid; the gap between the plates can be narrow enough to yield a relatively high capacitance. However, when dealing with granular or

[XEROACIP.L18]

pulverous media, a wider plate gap is necessary; and inaccuracies can be introduced by changes in the enclosed medium. Furthermore, as the fluid absorbing medium becomes increasingly saturated, the relationship between the

5   dielectric value and fluid concentration becomes less linear. As a consequence, accuracy of fluid concentration measurement suffers.

Another problem of relying on changes in the dielectric properties of a surrounding medium is that impurities

10 contained in the water produce significant changes in the dielectric constant which are not easily determined. Thus, the presence of salts will produce the same effective capacitance as a larger volume of water.

By accurately monitoring moisture levels in cultivated

15 land in order to provide optimum irrigation, significant gains can be achieved in water and energy conservation. The control of sprinklers, pumps and other irrigation equipmen from moisture monitors embedded at plant root-level has almost become a necessity in the water-poor sun-belt western

20 states.

Conventional moisture sensors of the type described above are not only inaccurate under certain conditions, but are difficult to embed in the ground due to their fragile plate configuration and internal electronic components.

25 There is a need for a more sensitive type of soil moisture monitor packaged in an easily embedded, durable, compact enclosure.

- 3 -

SUMMARY OF THE INVENTION

It is the object of the present invention to overcome or substantially ameliorate the above disadvantages.

There is disclosed herein a device adapted to determine the concentration of water in the earth, comprising:

first and second thin conductive layers having a planar configuration and disposed in adjacent relationship to define first plates of first and second capacitances,

a dielectric material covering the first and second thin conductive layers and defining the dielectric in the first and second capacitances,

the moisture in the earth defining the second plates of the first and second capacitances and defining the connections between the second plates in the first capacitances and the second plates in the second capacitances, and

means for introducing an energizing potential between the first and second thin conductive layers.

There is further disclosed herein a device adapted to determine the concentration of water in the earth, comprising:

a thin conductive layer defining the first plate of a first set of capacitors, said first set of capacitors comprising one or more capacitors,

a thin dielectric layer covering the thin conductive layer and defining the dielectric in the first set of capacitors, said thin dielectric layer being uniformly disposed on the thin conductive layer,

conductive terminal means disposed relative to the thin conductive layer to inhibit any capacitive relationship with the thin conductive layer and to provide a terminal to connect to moisture in the earth which defines the second plates of the said first set of capacitances, the capacitance of said first set of capacitances being dependent upon the amount of moisture in the earth,

potential means for applying a potential between the thin conductive layer and the terminal means,

a second conductive layer disposed in relatively close relationship to the first conductive layer,

a second dielectric layer disposed on the second conductive layer, said first and second conductive layers being co-planar and the first and second dielectric layers being substantially uniform,

the moisture in the earth defining second plates in a second set of capacitors with the second conductive layer defining the first plate in the second set of capacitors, the capacitance of said second set of capacitors being dependent on the amount of moisture in the earth, said second set of
5   capacitors comprising one or more capacitors,

the potential means also applying potential between the first and second conductive layers.

In the preferred arrangement, the detector circuit is an oscillator circuit designed to have an operating frequency no greater than 20 KHz.
10   The reactance is determined by the equation:

$$X_C = \frac{1}{2\pi f c}$$

where X_C is the reactance of the circuit, f is the frequency and c is the capacitance. Thus, the lower the frequency is,

STA/1383w

the higher the reactance will be. For higher frequencies, the circuits reactance will be lower and thus the effect of the reactance of the surrounding medium on the circuit operation will be greater.

5   The oscillating frequency of the circuit will be determined in part by the impedance between the two electrodes. This impedance will be determined by the unchanging dielectric constant of the material covering at least one of the electrodes, and the total surface area of

10   the water droplets in contact with the surface of the material between the two electrodes. The electrodes are preferably situated relatively close together to reduce the resistance of the water droplet paths, the number of which will be proportional to the moisture level of the

15   surrounding material.

Thus the apparatus can be designed for embedding in a granular material such as soil to measure its moisture content in a manner substantially independent from the dielectric constant of the material.

20   Traces or paths of water will form between the first electrode and the hydrophobic dielectric coating or layer of the second electrode. The impedance between the electrodes will therefore vary according to the moisture level of the soil, since the number of water paths or traces will

25   increase as the moisture level increases. This substantially eliminates or minimizes the effects of changes in the dielectric constant of the surrounding medium, since the traces of water contacting the dielectric coating of the second electrode act as one slate of a point capacitor, with

30   the insulator acting as the dielectric and having the second

[XEROACIP.L18]

electrode as their common plate. The capacitance will therefore be a function of the number of water traces between the first electrode and the dielectric layer and the thickness and dielectric constant of the dielectric layer.

5 The capacitance will rise with increasing moisture content to a maximum value determined by the area of the insulated electrode.

The geometry and relative positioning of the two electrodes is chosen so that the sensor can be easily

10 embedded in the material such as soil and so that the effect of the dielectric constant of the surrounding material is minimized - i.e. no significant capacitative effects occur directly between the two electrodes through the soil or other surrounding material. This can be done, for example,

15 by arranging the electrodes at a sufficient spacing to minimize such effects or by placing the first electrode on the exposed surface of the dielectric coating layer of the second electrode, so that the capacitance between the plates is only through the dielectric layer which has a fixed

20 dielectric constant.

In another arrangement, the two electrodes may be arranged side by side within an insulating coating covering both electrodes so that conductive paths of water droplets can be formed between positions on the coating covering the

25 two electrodes. These will form series capacitors through the dielectric coating to the respective underlying electrode.

[XEROACIP.L18]

Due to the lower dielectric constant of the insulating
or dielectric coating, as well as the controlled thickness
of the coating, the point capacitances formed by the water
droplets through the dielectric coating show a significantly
5   higher impedance than any undesirable capacitance
established through the surrounding medium. As a result,
the effect of these stray capacitances is minimized, as well
as the effects of impurities in the solution.

In the preferred embodiment of the invention the sensor
10   forms the reactive component for controlling the frequency
of an astable multivibrator or other oscillator whose output
frequency varies according to the impedance of the sensor,
and thus according to the moisture level of the surrounding
material. As the moisture level goes up, the number of
15   conductive paths increases, and the sensor capacitance
increases so that the resultant oscillator output frequency
drops.

A suitable frequency detection circuit may be provided
to detect the output frequency and produce a control signal
20   if it rises above a predetermined level corresponding to a
predetermined moisture level at which sprinklers are to be
operated. The control signal can be used to turn on
sprinkling or irrigation equipment, for example, and a timer
or further control signal produced when the frequency falls
25   below a further predetermined threshold maybe used to turn
off the equipment.

[XEROACIP.L18]

The sensor in the preferred embodiment is a flat, strip like device which can be easily embedded in the soil, and is preferably connected to a remote detector circuit to allow the moisture level to be monitored easily.

5   The aforementioned technique provides a highly accurate sensor due to the high value of capacitance which results from the summing of the various point capacitances, and the minimizing of the changes in the surrounding medium.

BRIEF DESCRIPTION OF THE DRAWINGS

10   The present invention will be better understood from the following detailed description of some preferred embodiments of the invention, taken in conjunction with the accompanying drawings in which like reference numerals refer to like parts, and in which:

15   Figure 1 is a front elevational view of a soil moisture sensor according to one embodiment of the invention with a section of the wall cut away to show the internal configuration;

Figure 2 is a top plan view of the sensor;

20   Figure 3 is a diagrammatical interpretation of the point of contact between a water droplet and the dielectric-coated electrode;

Figure 4 is a cross-sectional view of a sensor in an alternative embodiment;

25   Figure 5 is an electrical diagram of the sensor circuitry;

Figure 6 is a perspective view of a sensor according to another embodiment of the invention; and

Figure 7 is a cross-section on the lines 7-7 of Figure

30 6.

[XEROACIP. L18]

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

A first embodiment of the invention is illustrated in Figures 1, 2, 3 and 5 of the drawings.

Referring now to Figure 1, a soil moisture sensor 1,
5 packaged in a generally cylindrical enclosure 2, is embedded in a porous plant-growing medium 3 preferably at root level. A first, exposed electrode 4, comprises the bottom of enclosure 2. A second, insulated electrode 6 comprises the cylindrical wall of enclosure 2 and is coated on its exposed
10 cylindrical surface by a thin layer of hydrophobic, dielectric material 5 such as glass, porcelain or other vitreous compound, a synthetic resin polymer (e.g. polytetrafluoroethylene) or a thermosetting resin (e.g. one of the polymerized epoxides).

15 Insulated wires 7 and 8 respectively connect exposed electrode 4 and insulated electrode 6 to a printed circuit board 9 carrying control circuitry of the sensor which is described in more detail below in connection with Figure 5.

The two electrodes 4 and 6 together make up a complex
20 impedance dependent on the moisture level of the surrounding medium 3. Traces or droplets of water containing dissolved impurities will be present in the medium 3 to an extent dependent on the moisture level, and these traces will contact one another to form conducting paths between
25 electrode (4) and the dielectric coating as generally illustrated at 12, 13, 14 and 15 in Figure 1 between the exposed electrode 4 and the insulated electrode 6. These paths are only partially shown in Figure 1 for reasons of clarity but each droplet path will in practice form a
30 continuous trace from one electrode to the other. Point

capacitances are formed at the point 17, 18, 19, 20 and 21 at which each droplet path touches the dielectric layer 5 between those points and the opposing portions of the insulated electrode 6 as the opposite plate. The number of

5   capacitors formed by such droplets will increase as the moisture level increases, thus increasing the overall capacitance of the sensor, effectively swamping any effects of the dielectric constant of the surrounding medium. The complex impedance formed between the water droplets

10   electrode thus functions as an RC circuit, as indicated in Figure 5, with the capacitance related to the sum of all droplet point capacitances and the small resistance related to the resistive factor introduced by the conductive paths created by the water droplets laden with dissolved

15   impurities. As previously stated, the effect of the resistive factor is minimized through choice of geometry and frequency. This impedance will be directly related to the moisture level in the surrounding medium, and can be

20   used in a suitable detector circuit to produce an output proportional to the moisture level.

The sensor is arranged to eliminate or minimize the effects of changes in the dielectric constant of the surrounding medium with changing moisture level. This is done be designing the electrodes to avoid or minimize any

25   capacitative effects between the electrodes through the surrounding medium, and by arranging the operating voltage and frequency of the detector circuitry to minimize any build up of a field into the surrounding medium. This maximizes the effect of the impedance formed between the

30   droplet points on the outer surface of the dielectric layer

and through the dielectric layer to the insulated electrode. Thus, there is substantially no capacitative effect taking place between the electrodes through the surrounding medium itself, and the major impedance between the electrodes is

5 only through the dielectric layer which has a fixed dielectric constant. Thus the effect of increasing moisture level in the material surrounding the sensor is found to be substantially linear, and becomes more linear as the saturation level approaches 100 percent. This is unlike

10 previous sensor arrangements where both electrodes are exposed to the surrounding medium, so that the sensor is liable to become less linear as the moisture level reaches saturation.

In the embodiment of Figure 1, capacitative effects

15 between the electrodes are minimized by the non facing arrangement of the electrodes. The detector circuit operating characteristics will now be explained.

The complex impedance of the sensor determines the vibration frequency of an astable multivibrator 22. As the

20 moisture level of the soil increases, the resulting increase in the number of point capacitances forming on the coated electrode 6 causes a drop in the oscillation frequency of astable multivibrator 22. A potentiometer 23 can be adjusted to set the multivibrator frequency level at which a

25 solenoid driver circuit is activated and deactivated, as described below.

The sensor is designed specifically so that changes in dielectric constant of the surrounding medium have a minimal effect. By making the multivibrator frequency relatively low, suitably in the 20 KHz range or lower, and the

5   thickness of the dielectric relatively high, preferably in the 5-10 mm range, so that ehs sensor reactance is also relatively high compared to that of the medium, the effect of changes in reactance of the surrounding medium is effectively swamped or minimized and the reactance of the

10   sensor will dominate.   The operating voltage of the circuit of Figure 5 is preferably below 12 volts, and is of the order of 8 volts in the preferred embodiment.   The frequency and dielectric thickness may be modified in alternative embodiments while maintaining the desired

15   relative relationship between the sensor and surrounding medium reactance.

As shown in Figure 5, the electrodes 4 and 6 forming the sensor impedance 25 which functions as an RC circuit are connected to astable multivibrator 22 so as to determine the

20   oscillation frequency of the multivibrator. The multivibrator is provided on chip 10 which is mounted on the printed circuit board 9 as shown in Figure 1.

The multivibrator 22 has its output connected to a first monostable multivibrator 26 which functions as a

25   frequency discriminator with a threshold determined by the setting of potentiometer 23. The output of multivibrator 26 is connected to the input of a second monostable multivibrator 28 which functions as a filter. The inverted or Q output of the second monostable 28 is connected to one

30   input of AND gate 30. Gate 30 has its output connected to

solenoid driver circuit 31 which is connected to a light
switching diode 11. Diode 11 is mounted on the printed
circuit board 9 so as to be visible through a window in
enclosure 2 and will light up when circuit 31 is activated.

5   The output of astable multivibrator 22 in the
illustrated embodiment is also connected through a timing
circuit consisting of monostable multivibrator 27 with its
threshold determined by the setting of potentiometer 24, and
a further monostable multivibrator 29 connected to the

10 output of the first monostable 27 and having its inverted or
$\bar{Q}$ output connected to AND gate 30.

    Multivibrators 27 and 29 are connected in the non-
retriggerable mode and are set to time out at a
predetermined interval, as described in more detail below.

15 The multivibrators 27 and 29 and AND gate 30 are not
essential to the operation of the circuit and are inserted
to provide an arbitrarily long overriding shut off interval,
as described below. Thus in an alternative, simplified
embodiment the $\bar{Q}$ terminal of multivibrator 28 is connected

20 directly to solenoid driver 31, as indicated by dotted lines
in Figure 5, and multivibrators 27 and 29, together with AND
gate 30 may be eliminated from the circuit.

    The operation of the basic circuit without
multivibrators 27 and 29 and AND gate 30 will first be

25 described.

[XEROACIP.L18]

The timing cycle of monostable multivibrator 26, which is connected in the retriggerable mode, is adjustable by means of potentiometer 23. Thus potentiometer 23 can be set for triggering the circuit when the moisture level falls
5   below a minimum threshold (DRY mode).

WET mode operation of the circuit will first be described. If the moisture level is above the minimum threshold, the pulse output of astable multivibrator 22 will have a period exceeding that of monostable multivibrator 26
10   (set by potentiometer 23). Thus monostable 26 will be allowed to time out during each cycle, and is then retriggered to produce a pulsed output to monostable multivibrator 28 which triggers it into the HIGH condition. This produces a low output at the $\bar{Q}$ terminal which holds the
15   power triac 31 in an OFF mode.

As the moisture level drops below the minimum threshold set by potentiometer 23, the period of the pulsed output from astable multivibrator 22 decreases until it is less than that of monostable 26. At this point the circuit 26 is
20   not allowed to time out and a steady state high output is produced. Therefore, no triggering pulse is applied to monostable 28 and it will be held in the low, reset mode. Thus, its $\bar{Q}$, inverted output will be high. At this point the power triac or driver 31 will be turned to the ON state.

Driver 31 is designed to control solenoid-controlled valves of the type commonly used with watering or irrigation equipment. Thus as soon as the moisture level falls below the predetermined minimum threshold, the watering equipment

5   is turned on.

The watering cycle may be controlled to be switched off after a fixed interval of watering time each time the monostable 28 produces a high output at its $\bar{Q}$ terminal. Alternatively, the monostables 26 and 28 could be arranged

10 such that the watering equipment is started at fixed intervals and shut-off only when a maximum desirable water level is reached. In this case potentiometer 23 would be set such that monostable 26 is allowed to time out to trigger monostable 28 into a high condition only when the

15 output period of astable multivibrator 22 exceeds a value corresponding to the maximum desired water level. The resultant low output at the $\bar{Q}$ terminal of monostable 28 could then be used to turn the watering equipment off. Thus the frequency discriminating upper part of the circuit shown

20 in Figure 5 can be arranged to turn watering equipment on when the minimum tolerable moisture level is reached or to turn the equipment off when a maximum desirable water saturation is reached. When used in either mode, a considerable conservation of water may be achieved while

25 maintaining ground moisture within an optimum range.

The light emitting diode 11 is provided to aid in adjustment of potentiometers 23 and 24. Both the potentiometers and the diode are accessible through sealable holes in the top of enclosure 2. Thus, for example, the

30 sensor can be calibrated for a desired moisture level by

adding controlled quantities of moisture to the surrounding
medium and adjusting potentiometer 23 so that the light goes
off when the desired moisture level is reached. The
moisture threshold, whether set up for a minimum or maximum
5   moisture level, can be adjusted both in the field and during
manufacture, as desired.

The operation of the full circuit including the timing
circuit and AND gate 30 shown in Figure 5 will now be
described. As mentioned above, these circuit components are
10   not essential to operation of the device but are provided
only as an optional modification for reducing water run off
losses.

In the circuit shown in Figure 5 the output of AND gate
30 will be high only if both inputs are high. Thus, if the
15   moisture level falls below the threshold set by
potentiometer 23 and the $\bar{Q}$ terminal of multivibrator 28 goes
high, the watering equipment will be switched on only if the
input from multivibrator 29 is also high.

Monostable multivibrators 27 and 29 are set by
20   potentiometer 24 into a nonretriggerable mode where
multivibrator 27 has predetermined pulsed output which goes
high at predetermined fixed intervals, setting the next
multivibrator high for a fixed interval so that its $\bar{Q}$ output
goes low for that period. This will hold the solenoid driver
25   off for a fixed interval even if the output of multivibrator
28 is high. The next time the $\bar{Q}$ output of multivibrator 29
goes high, the watering equipment will be turned on for a

[XEROACIP.L18]

fixed interval, then off again, then on again, and so on until the moisture level again rises above the threshold level so that the $\bar{Q}$ output of multivibrator 28 is low.

The periodic time outs of the watering cycle introduced by the multivibrators 27 and 29 will allow time for water to percolate into the soil, thus reducing run off losses significantly. The time interval can be set according to the time estimated to be necessary to allow full water percolation. For example, time outs of the order of 2 minutes may be set in a typical application. Thus, with the full circuit operating as shown in Figure 5, each time the solenoid diver is triggered ON by simultaneous high inputs to AND gate 30, it will be periodically triggered OFF again for repeated predetermined intervals by the timing out of multivibrator 29 to allow time for water percolation, until the point at which the moisture level again rises above the minimum level so that the other input to AND gate 30 goes low to hold the driver OFF.

The optional connection of the $\bar{Q}$ output of multivibrator 28 directly to the solenoid driver 30, eliminating the periodic time outs, is illustrated in dotted lines at 60 in Figure 5. In this arrangement, the AND gate 30 and the multivibrators 27 and 29 do not have to be included. Clearly alternative timing means may be provided if desired to provide time outs in the watering cycle. If required, provision may be made for the insertion of some hysteresis in the frequency discriminator part of the circuit, for the reduction or prevention of solenoid chatter at the set point or threshold.

The relative configuration and geometry of the two
electrodes of sensor 1 need not be as shown in Figure 1, but
is chosen so as to minimize the effects of changes in the
dielectric constant of the surrounding medium while
5   producing a sensor of sufficient rigidity for easy embedding
in the medium. Ease of manufacture is also a factor in
choice of electrode configuration.

The electrode arrangement is preferably such that the
impedance factor introduced by the resistance of the
10 conductive paths through the medium 3 between the exposed
electrode and the insulated electrode is considerably less
than the impedance produced by the point capacitors formed
on the insulated electrode at the end of the conductive
paths. This means that the electrodes should not be too far
15 apart, so that the resistive factor can be arranged to be
insignificant as compared to the capacitative factor and the
total effective impedance varies substantially linearly with
the moisture level of the soil, with the linearity
increasing with increasing moisture content. This can be
20 done both by minimizing the conductive path length from the
exposed electrode to the insulated electrode, and by
providing a relatively large exposed area of the insulated
covering of the insulated electrode for formation of point
capacitances. Direct capacitance between the electrodes
25 through the dielectric or insulating layer is also minimized
in the preferred embodiments, and is swamped by the effects
of the point capacitances formed by the water droplet paths.

[XEROACIP.L18]

Figures 4, 6 and 7 show a possible alternative
electrode configurations for the sensor. In each of these
embodiments the electrodes will be connected in the circuit
of Figure 5 and will function in the manner described above.

5   In Figure 4 insulated electrode 34 is covered by an
insulating or dielectric coating 33 with exposed electrode
32 provided as a thin metal strip applied to the outer
surface of coating 33 so as to leave the major area of the
coating exposed to the surrounding material. The sensor
10   assembly may itself be in the form of a thin strip which
projects at one end into a housing containing the frequency
discriminating circuitry (not shown). Alternatively, wiring
may be provided for connecting the electrode to remote
detector circuitry. The sensor of Figure 4 operates in the
15   same manner as described above to respond to conductive
water droplet paths formed between the exposed faces of
electrode 32 and layer 33.

In another alternative arrangement, the insulated
electrode may be split in two with the exposed electrode
20   coplanar with and sandwiched between the resultant two
insulated electrode halves.

Another alternative electrode configuration for the
sensor is shown in Figures 6 and 7. As shown in Figures 6
and 7, electrode assembly 40 comprises a pair of flat,
25   striplike electrodes 42, 44 extending side by side with a
small gap 46 between them. The electrodes are embedded in
an envelope 45 of a suitable dielectric material, such as
polyethylene or the like. The entire envelope strip is very
thin, suitably of the order of credit card thickness, so
30   that it can easily be embedded in a material, such as soil,

to measure the moisture content. The electrodes may comprise thin strips of copper or equivalent materials.

The two electrodes are connected via leads 46, 48 in a remote detector circuit as shown in Figure 5. Thus the
5   entire detector circuit does not have to be embedded in the ground with the electrode assembly.

By arranging the electrodes with a large, dielectric covered area facing the surrounding medium and only a relatively small area of the electrodes facing one another
10   across the small gap 46, as well as having the oscillator operating frequency very low, as described above the effect of the changes in the dielectric constant of the surrounding medium will be swamped or minimized as will any direct capacitance between the two electrodes. Water droplet paths
15   50 will form from points on the envelope above one electrode to points directly above the other electrode, as indicated in Figure 7. The number of paths 50 will depend on the moisture content of the surrounding material. Point capacitances are formed at the points each droplet path
20   touches the dielectric envelope, between the respective points and the opposing portions of the respective underlying electrode. Thus each droplet will have the effect of two capacitors connected in series with a resistance dependent on the water droplet conductive path.
25   As in the previous embodiments, the resultant complex impedance connected in the oscillator circuit of Figure 5 will determine the vibration frequency of astable multivibrator 22. As the moisture level goes up, the number of series connected point capacitors increases and the
30   output frequency of the astable multivibrator goes down.

[XEROACIP.L18]

The moisture monitor with an electrode configuration as shown in Figures 6 and 7 will therefore operate in the same way as described above connection with Figure 5, to give an output indicative of the moisture content of the surrounding material. Because of its thin, striplike form, it can easily be embedded in soil, for example, without having to dig out a hole first, and can be moved from one place to another to test for uniform watering.

Thus, the soil moisture monitors with electrode configurations as explained above are all designed to minimize the effects of changes in the dielectric constant of the surrounding medium by substantially reducing or avoiding any capacitance between the electrodes through the surrounding medium. At the same time, the effects of point capacitances formed via water droplet paths between the electrodes are maximized to swamp any effects of the dielectric constant of the surrounding medium. At least one electrode is enclosed or insulated from the surrounding medium, while the electrodes are preferably physically close together either in a non-facing relationship or with only a dielectric layer of fixed dielectric constant between them. The electrodes are connected in an oscillator circuit for controlling the output frequency according to moisture level, and the oscillator operating frequency is 20 KHz or less to minimize the build up of any field into the surrounding medium.

[XEROACIP.L18]

While the preferred embodiment of the invention has been disclosed, other embodiments may be devised and modifications made within the spirit of the invention and within the scope of the appended claims.

5

WHAT IS CLAIMED IS:
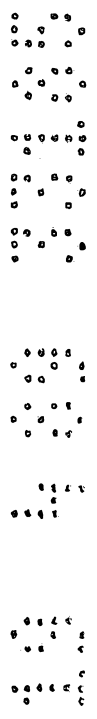
The claims defining the invention are as follows:

1.   A device adapted to determine the concentration of water in the earth, comprising:

first and second thin conductive layers having a planar configuration and disposed in adjacent relationship to define first plates of first and second capacitances,

a dielectric material covering the first and second thin conductive layers and defining the dielectric in the first and second capacitances,

the moisture in the earth defining the second plates of the first and second capacitances and defining the connections between the second plates in the first capacitances and the second plates in the second capacitances, and

means for introducing an energizing potential between the first and second thin conductive layers.

2.   A device adapted to determine the concentration of water in the earth as claimed in claim 1, wherein:

the first and second conductive layers being co-planar and the dielectric material on the first and second conductive layers being thin and substantially uniform.

3.   A device adapted to determine the concentration of water in the earth as claimed in claim 1, additionally comprising:

a frequency generation means responsive to the values of the first and second capacitances adapted to generate signals having a variable frequency in accordance with variations in such values, and

a control means responsive to variations in the frequency of said signals adapted to provide a controlled watering of the earth.

4.   A device adapted to determine the concentration of water in the earth as claimed in claim 3, wherein said control means comprises:

initiation means responsive to a first frequency of a relatively high value in a control signal provided by said generation means adapted to initiate watering of the earth, and

termination means responsive to a second frequency of said control signal of a lower value than said first frequency adapted to discontinue watering of the earth.

5.   A device adapted to determine the concentration of water in the earth as claimed in claim 3, wherein said control means comprises:

initiation means responsive to a first frequency in the signals of a relatively high value in a control signal provided by said generation means adapted to initiate watering of the earth, and

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termination means operative upon initiation of watering of the earth adapted to terminate watering of the earth should either a fixed time interval be completed or should said control signal have a frequency equal to a second frequency lower in value than the first frequency.

6. A device adapted to determine the concentration of water in the earth, comprising:

a thin conductive layer defining the first plate of a first set of capacitors, said first set of capacitors comprising one or more capacitors,

a thin dielectric layer covering the thin conductive layer and defining the dielectric in the first set of capacitors, said thin dielectric layer being uniformly disposed on the thin conductive layer,

conductive terminal means disposed relative to the thin conductive layer to inhibit any capacitive relationship with the thin conductive layer and to provide a terminal to connect to moisture in the earth which defines the second plates of the said first set of capacitances, the capacitance of said first set of capacitances being dependent upon the amount of moisture in the earth,

potential means for applying a potential between the thin conductive layer and the terminal means,

a second conductive layer disposed in relatively close relationship to the first conductive layer,

a second dielectric layer disposed on the second conductive layer, said first and second conductive layers being co-planar and the first and second dielectric layers being substantially uniform,

the moisture in the earth defining second plates in a second set of capacitors with the second conductive layer defining the first plate in the second set of capacitors, the capacitance of said second set of capacitors being dependent on the amount of moisture in the earth, said second set of capacitors comprising one or more capacitors,

the potential means also applying potential between the first and second conductive layers.

7. A device adapted to determine the concentration of water in the earth as claimed in claim 6, additionally comprising:

means responsive to a particular value for the first and second capacitances for obtaining a watering of the earth.

8.   A device adapted to determine the concentration of water in the earth as claimed in any one of the preceding claims, wherein:
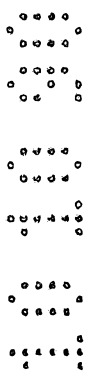
the moisture defining the connections between the second plates in the first capacitances and the second plates in the second capacitances having a resistance considerably less than the impedances provided by the fist and second capacitances.

9.   A device adapted to determine the concentration of water in the earth substantially as hereinbefore described with reference to Figs. 5 and 6 of the accompanying illustrations.

DATED this TWENTY-SEVENTH day of SEPTEMBER 1990
Aquametrics, Inc.

Patent Attorneys for the Applicant
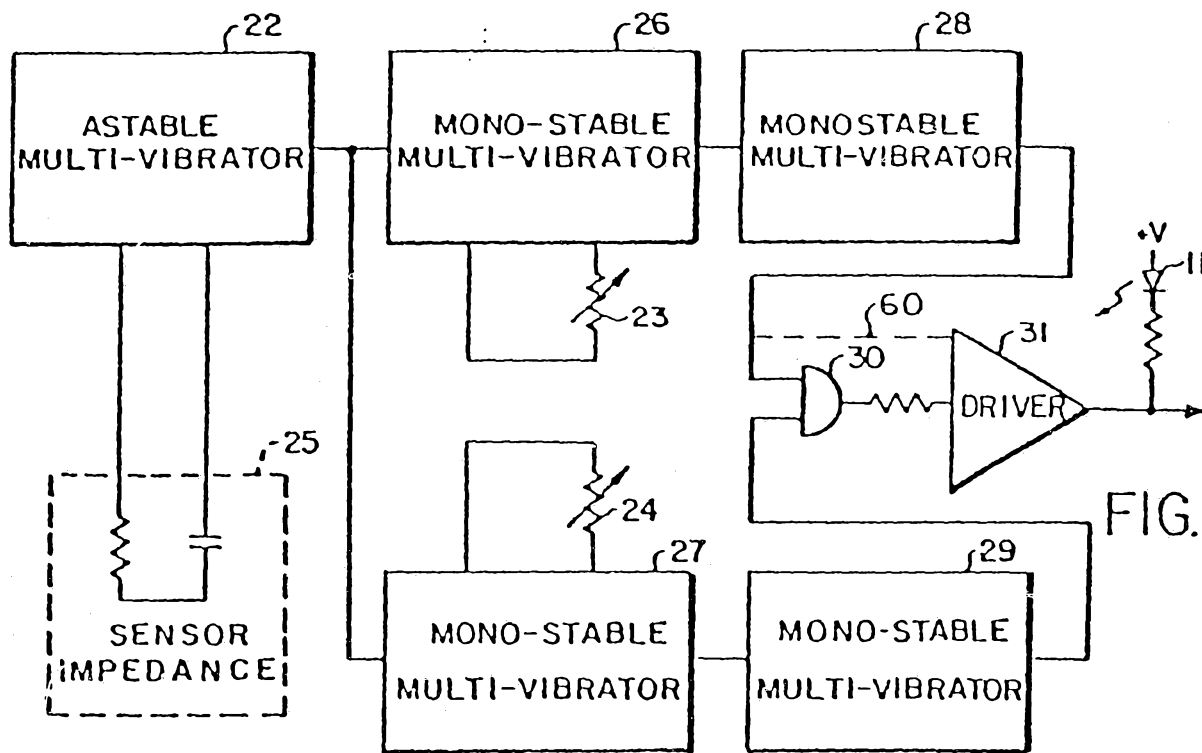SPRUSON & FERGUSON

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FIG. 2

FIG. I
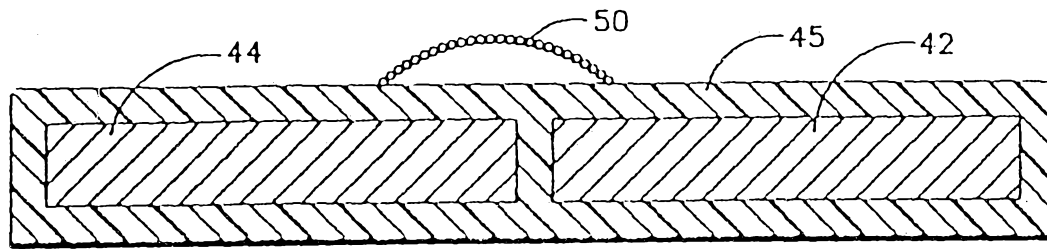
FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7