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[54] **AUTOMATIC INFUSION APPARATUS**
11 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** ..... **340/239 R,** 128/DIG. 13
[51] **Int. Cl.** **G08b 19/00,** A61m 5/16, G05d 7/00
[50] **Field of Search** 340/239; 137/486; 222/59; 128/DIG. 13, 208

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ABSTRACT: An automatic infusion apparatus in which a timer is started each time a drip of infusion fluid is delivered. A circuit including two AND gates responds to the timer and to a drip detector to determine qualitatively whether the next drip occurs before or after a timing period. Each AND gate triggers a respective monostable timing circuit controlling a motor for altering an adjustable valve to adjust the drip rate by a single increment. The motor is prevented from operating if the next drip occurs slightly after the timing period.

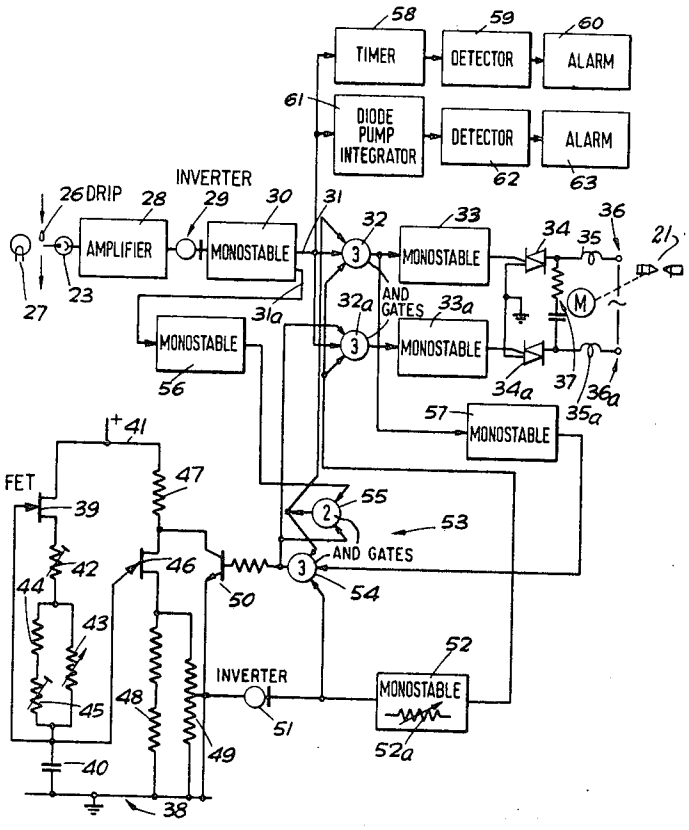


Fig. 1.

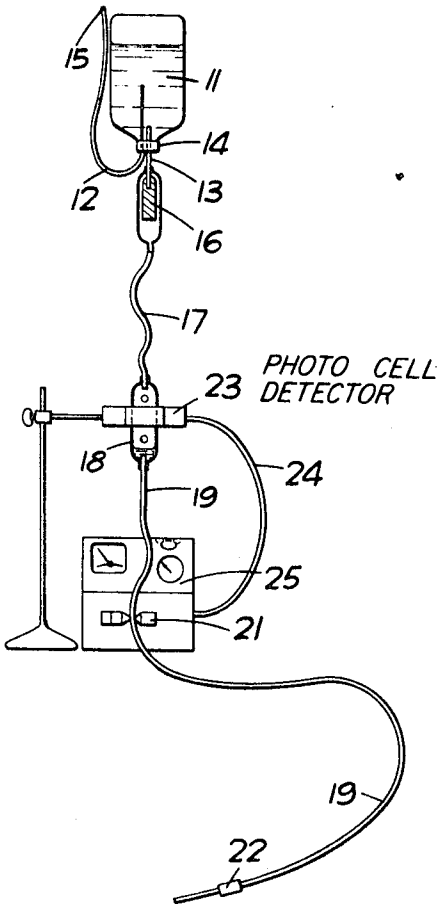
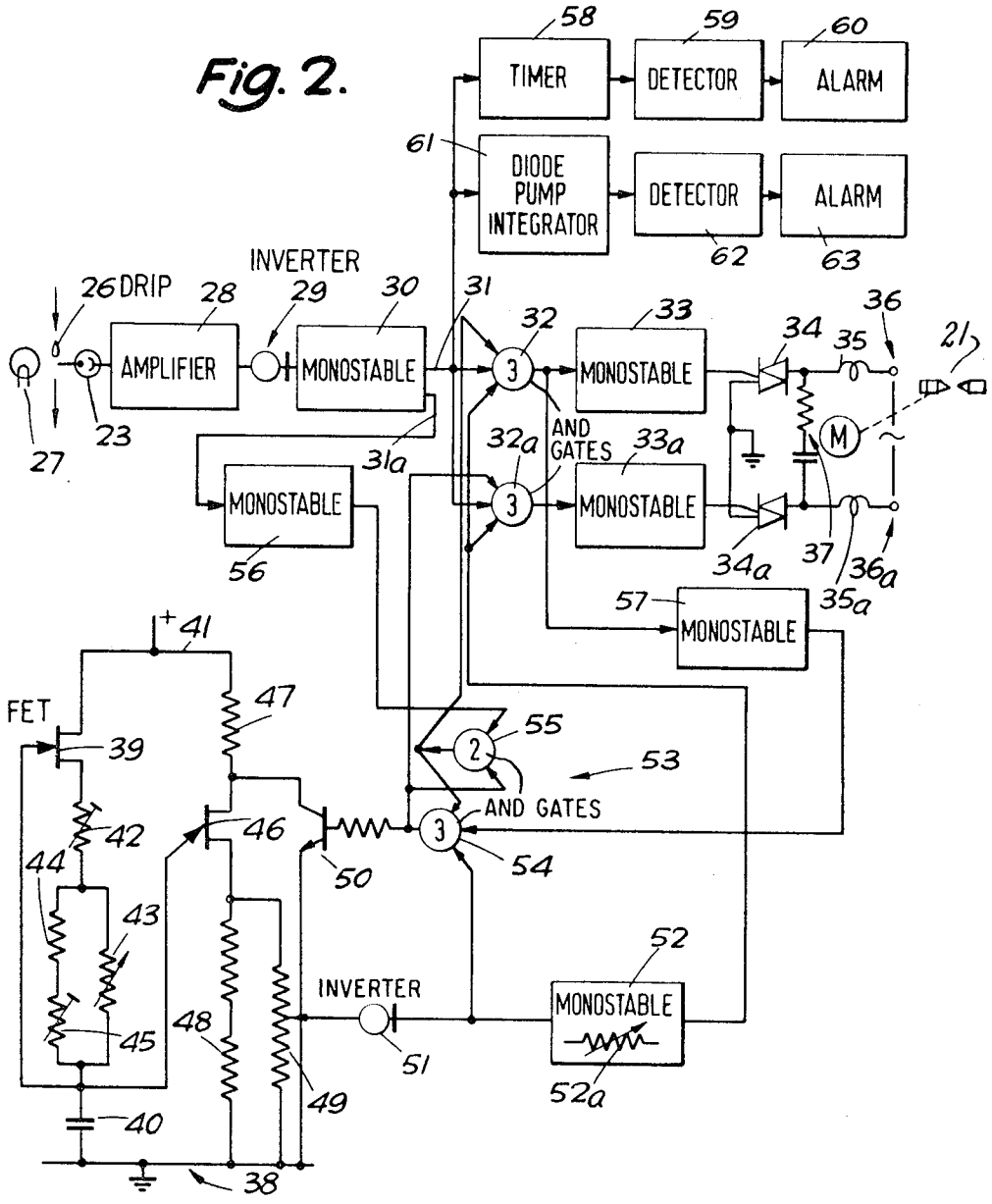


Fig. 2.


58
59
60
TIMER
DETECTOR
ALARM
61
DIODE PUMP INTEGRATOR
DETECTOR
ALARM
62
63
INVERTER
26 DRIP
28
29
30
31
32
33
34
35
36
21
AMPLIFIER
MONOSTABLE
3
MONOSTABLE
M
23
27
31a
32a
AND GATES
33a
MONOSTABLE
3
MONOSTABLE
56
34a
37
36a
35a
57
MONOSTABLE
+41
47
FET
39
55
2
53
AND GATES
42
46
3
54
44
50
43
45
48
49
INVERTER
MONOSTABLE
52
52a
51
40
38

AUTOMATIC INFUSION APPARATUS

FIELD OF THE INVENTION

This invention relates to automatic infusion apparatus.

BACKGROUND TO THE INVENTION

Infusion apparatus is in use throughout the world for giving to patients infusions of blood, drugs, saline solutions and the like. It is known that one of the most important considerations in giving infusions is the accurate control of the rate of infusion. The ability of a patient to absorb an infusion depends partly on his own metabolism and partly on the infusion fluid. For example, different patients require the infusion to be given at a different rate but also different infusion fluids must be given at different rates to the same patient.

It is at the present time appreciated that the automatic control of medical infusions is desirable, especially for infusions of drugs at low drip rates of the order of a few drips per minute. One object of the present invention is to provide an improved form of apparatus which is particularly suitable for controlling the delivery of infusion fluid at low drip rates.

BRIEF SUMMARY OF THE PRIOR ART

Known forms of automatic infusion apparatus are based on comparing a quantitative measure of the drip rate with a reference signal, using sampling and holding techniques, or on the use of a pulse generator generating a reference signal of frequency equal to the desired drip rate. In general, apparatus based on these techniques suffers from one or more important disadvantages, namely, unsuitability for use over a large range of drip rates, lack of control of very low drip rates (such as four drips per minute), and unsuitability for adaptation to solid-state electrical devices. The present invention is generally directed to avoiding these disadvantages.

SUMMARY OF THE INVENTION

The main basis of the present invention is the avoidance of any need to make a quantitative determination of the drip rate or any parameter thereof, and instead to alter the drip rate (preferably by small increments) according to whether the time between selected drips (usually immediately successive drips) is qualitatively greater or less than a predetermined time.

According to the invention, in or for infusion apparatus comprising means for forming infusion fluid into successive drips and a delivery device which is adjustable to vary the drip rate and thereby the rate at which the infusion fluid is delivered, there are provided means for detecting the drips, a timer adapted to be started in response to the occurrence of a drip and to provide a predetermined timing period and control means for decreasing the drip rate if a subsequent drip occurs before the end of the timing period and for increasing the drip rate if the subsequent drip occurs after the end of the timing period. Preferably the timer is arranged to be restarted in response to each drip and the said subsequent drip is the next drip after the start of the timing period.

By using the actual time between drips and a predetermined timing period corresponding to the desired interval between drips any need to use average values of a drip rate or pulse generators providing pulses at the desired drip rate (as has been necessary with prior devices) is avoided.

It is preferred to provide means for inhibiting any change in the drip rate if the said subsequent drip occurs within a further period after the end of the aforementioned timing period. This permits a small error in the drip rate while avoiding any need to correct the drip rate after each drip.

The adoption of qualitative measures for controlling the drip rate makes possible the use of relatively simple logical circuits for causing changes in the drip rate; accordingly, there may be means responsive to the occurrence of the said subsequent drip to provide a control signal, means under the control of the timer to provide a first signal during the timing

period and a second signal after the end of the timing period and, for causing the decrease and increase of the drip rate respectively, a first logical AND circuit responsive to the control signal and the said first signal and a second logical AND circuit responsive to the control signal and the said second signal. For performing the function of inhibiting changes in the drip rate, means under the control of the timer may provide at times other than during the said further period a third signal and the AND gates are operative to cause changes in the drip rate only during their reception of the third signal.

It is preferred that the control means operates to change the drip rate by only a single (small) increment at a time. This avoids the delivery of infusion fluid at a high rate, which can be extremely undesirable, even when there is a large disparity between the actual and desired drip rates, for example, when an infusion is started.

The control means may comprise two circuits each arranged when triggered to cause the driving of a motor controlling a clamp on a flexible tube in the delivery device in a respective predetermined sense for a predetermined time, one circuit being arranged to be triggered if the subsequent drip occurs within the aforementioned timing period and the other circuit being arranged to be triggered if the said subsequent drip occurs after the end of the further period; means may be provided to inhibit the triggering of the circuits if the said subsequent drip occurs within the further period. Accordingly, if the drip rate is too fast or too slow the clamp is adjusted by a predetermined increment. After the adjustment, if the drip rate is still in error a further increment of movement on the clamp will tend to reduce further the disparity between the actual and desired drip rates.

The aforementioned timer may comprise a capacitor, a triggerable constant current generator for charging the capacitor and means responsive when the voltage across the capacitor attains a predetermined value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a drawing illustrating an infusion apparatus; and

FIG. 2 is a diagram, partly schematic, of a control circuit for use with the apparatus of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 is shown a glass bottle **11** of blood or other infusion fluid supported in an inverted position. Two tubes **12** and **13** pass into the neck of the bottle **11** through a bung **14**. One tube **12** is an air vent which may include an air valve which is opened when the pressure inside the bottle **11** falls and is closed again when that pressure rises. The free end **15** of the tube **12** is open and is above the level of fluid in the bottle **11**. The other tube **13** carries the infusion fluid from the bottle **11** to a filter chamber **16**. A further tube **17** connects the filter chamber to a drip chamber **18** having transparent walls. A further flexible tube **19** connects a lower end of the drip chamber through a motor-driven clamp **21** to a dispenser **22**.

The apparatus so far described, with the exception of the air valve, constitutes a conventional infusion apparatus known as a "recipient set," or sometimes, as a "giving set." Disposed adjacent the drip chamber **18** is a photoelectric detecting apparatus **23** connected by an electrical connection **24** to a control system in a cabinet **25**. The detector and the associated control system are shown in more detail in FIG. 2.

Referring now to FIG. 2, there is shown the detector **23** illustrated as a photoelectric cell disposed to sense the passage of drips **26** in the drip chamber between the detector **23** and a suitable lamp **27**.

The detector is preferably situated just below the end of the tube **17** where it leads into the drip chamber so that drips in free fall modulate the light beam between the lamp **27** and the cell **23** (which may be a silicon photodiode) so as to provide in response to the passage of each drip a signal which is appropriately amplified and shaped in an amplifier **28** to provide an output pulse. Pulses from the amplifier **28** are fed through

an inverter 29 to a monostable circuit 30. This circuit has two outputs 31 and 31*a* which provide complementary signals: that is to say when the output 31 provides a signal corresponding to logical zero ("0") the output 31*a* provides an output corresponding to logical unity ("1"); these signals are in fact provided in the quiescent state of the monostable circuit 30.

The pulse length of the monostable circuit 30 is in the range 1.4 to 1.8 milliseconds.

The output 31 of the monostable circuit 30 leads to one input of each of two gates 32 and 32*a* each of which has its output coupled to the trigger input of a monostable circuit 33 and 33*a* respectively. When triggered each monostable 33 and 33*a* provides a pulse of predetermined length to the trigger input of a corresponding triac (bidirectionally controllable rectifier) 34 or 34*a*. The cathodes of the triacs are coupled to ground and the anodes are coupled each through a coil 35, 35*a* to corresponding input terminals 36 and 36*a* across which an alternating current appears. The anodes of the triacs 34 and 34*a* are coupled by a phase-splitting circuit 37 comprising a resistor and a capacitor.

The coils 35 and 35*a* are drive coils for a synchronous motor M used to drive the clamp 21 disposed about the tube in the infusion set. This regulates the pressure drop at the clamp and accordingly the drip rate and the rate of delivery of the infusion fluid to the patient. It will be readily appreciated that the circuits driven by the monostable devices 33 and 33*a* can be replaced by any suitable equivalent according to the type of motor used. The use of timed pulses from the monostable circuits 33 and 33*a* ensures that the position of the clamp is altered in increments. If the monostable circuit 33 is triggered, then the motor is driven for a predetermined period in one sense so as to increase the pressure on the tube 19 whereas if the monostable 33*a* is triggered the motor is driven for an equivalent increment in the opposite sense to release pressure on the tube 19. If neither monostable circuit 33 or 33*a* is operated no adjustment is made to the clamp and hence no adjustment is then made to the drip rate.

A timer 38 includes a junction field-effect transistor 39 arranged as a constant current source for charging a capacitor 40. It will be appreciated that if a capacitor is charged from a constant current source, the rate of change of the voltage stored by the capacitor is likewise constant. The field effect transistor 39 is coupled between a 20-volt supply line 41 and a resistive circuit that leads to one plate of the capacitor 40 whose other plate is earthed. The resistive circuit includes an adjustable trimming resistor 42 in series with a parallel network that in one branch has a potentiometer 43 and in a further branch has a fixed resistor 44 and an adjustable trimming resistor 45. The potentiometer 43 is adjustable to determine the current through the field effect transistor and thereby the rate of change of the voltage across the capacitor 40 and the timing period' of the timer. Coupled to the nonearthed plate of the capacitor 40 is the emitter of a unijunction transistor 46 of which one base is coupled through a resistor 47 to the supply line 41 and whose other base is coupled through a resistive network 48 to earth. Across the resistive network is a potentiometer 49 of which the slider constitutes the output terminal from the timer 38. Between the upper base of the unijunction transistor 46 and earth is the collector/emitter circuit of a transistor 50 which when rendered conductive by an appropriate signal at its base renders the capacitor 40 discharged and thereby inhibits the timing circuit from starting another timing period.

The slider of the potentiometer 49 is coupled through an inverter circuit 51 to the input of a monostable circuit 52. The purpose of this monostable circuit is to provide, after the timing period provided by the timer 38, a further period within which the occurrence of a pulse subsequent to that causing the starting of the timer's timing period will not result in any change in the drip rate. This has the advantage of avoiding the need to alter the drip rate after each pulse if the drip rate is approximately correct.

It is desirable to vary the further period if the apparatus is to be used with a wide variety of drip rates. For this purpose the monostable circuit 52 is adjustable conveniently by means of an adjustable resistor 52*a*, which is provided at some convenient point in the circuit 52 and is ganged to the adjustable resistor 43. It is possible to employ a "further period" of the order of 760 milliseconds where the drip rate is of the order of four drips per minute and a "further period" of the order of 18 milliseconds where the drip rate is of the order of 60 drips per minute; periods of 350 milliseconds and 50 milliseconds respectively are preferred.

The output of the adjustable monostable timing circuit 52 is fed to an input of each of the gates 32 and 32*a*.

For controlling the operation of the timer 38 there is provided a memory 53; this comprises essentially two gates interconnected to form a bistable circuit. The output of the gate 54 is coupled to the base of the transistor 50 so that when a logical unity output from the gate 54 exists (when the memory is "set") the transistor is conductive and operation of the timer is inhibited. The output from the gate 54 is connected to one input of the gate 55 and also to a third input of the gate 32*a*. The output of the gate 55 is coupled to one input of the gate 54 and also to a third input of the gate 32. The second input of the gate 55 receives an output from a monostable circuit 56 of which the trigger input is coupled to the output of the monostable 30. The timing period of the monostable circuit 56 is very short, preferably of the order of 3.6 milliseconds.

A second input to the gate 54 is coupled to the output of the inverter 51 and a third input of the gate 54 is coupled to the output of a delay 57 whose input is coupled to the output of the gate 32 or to some suitable point in the subsequent monostable circuit 33.

The operation of the control circuit as far as the regulation of the drip rate is concerned proceeds as follows.

It will be assumed that the timer 38 has been started in response to the occurrence of a previous drip. If a drip is detected so that an output signal at the output 31 of the monostable circuit 30 occurs at the same time as the capacitor 40 attains the predetermined value marking the end of the first timing period, there is a logical zero output at the output of the adjustable monostable circuit 52. This logical zero output inhibits both the gates 32 and 32*a* from triggering the monostable circuits 33 or 33*a* respectively so that the motor is not operated and no change is made to the drip rate. This is the case provided that the pulse occurs within the period determined by the adjustable monostable circuit 52.

If the drip occurs later, so that the output from the adjustable monostable circuit has returned to its normal unity state, then the inputs from both the monostable 30 and the monostable 52 to the gates 32 and 32*a* will all be at logical unity. In addition however the memory 53 will be set and all the inputs to the gate 32*a* will be at logical unity thereby effecting the triggering of the monostable 33*a* and the drive of the motor 36 to increase the drip rate by one increment.

If on the other hand the drip arrives early that is to say before the voltage across the capacitor 40 reaches the predetermined value, associated with the end of the timer's timing period, then the following occurs. The memory is reset because it needs to be set in response to a pulse from the inverter 51; the output of the gate 54 is at logical zero as is the corresponding input to the gate 32*a*. This inhibits the gate 32*a* from opening and prevents any triggering of the monostable 33*a*. However, the other gate 55 of the memory must have a logical unity signal at its output so that the other two inputs to the gate 32 are at logical unity. Since the normal output of the adjustable monostable 52 is likewise unity all the inputs to the gates 34 are at logical unity and the monostable 33 is triggered so as to cause the motor 36 to decrease the drip rate by one increment. The capacitor 40 charges until the output pulse from the monostable circuit 30 ends. The cessation of the output pulse from the gate 32 is caused to operate the monostable circuit 57 whose output, incident at the corresponding input to the gate 54, sets the memory 53.

Since the monostable circuit **56** is triggered in response to the output of the monostable **30**, provided that the period of the monostable **56** is greater than the period of the monostable **57**, after the clock memory is set a subsequent output from the monostable **56** is applied to an input of the gate **55** to reset the memory and thereby open the transistor switch **50** so that the timer can recommence timing. It is preferred therefore that the monostable delay **57** has a delay of the order of 1.8 milliseconds.

Several forms of alarm and indicating circuit are associated with the control circuit shown in FIG. **2**. An alarm denoting too slow a drip rate may readily be provided using a timer **58** which is reset and restarted in response to each drip and which has a timing period of 30 seconds or more. If the timer reaches the end of its timing period a detector **59** senses that end and an alarm **60** is operated. A diode pump integrator **61** Lfed with a pulse in response to each drip may be arranged to operate an alarm **63** if the stored integration is too high, an excessive integration being sensed by a detector **62**.

The timer **58** and integrator **61** are operated by pulses taken from an output of the monostable circuit **30**, and may each be adjustable.

I claim:

1. In infusion apparatus comprising means for forming infusion fluid into successive drips and a delivery device for said infusion fluid, said delivery device including adjustable means responsive to corrective signals for varying the drip rate and thereby the rate at which the infusion fluid is delivered, control apparatus comprising: means for detecting the drips; a timer; means for starting the timer in response to the occurrence of a drip, said timer providing a predetermined timing period; and control means, coupled to said means for detecting and said timer, for tending to correct the drip rate in response to disparity between the occurrence of a subsequent drip and the end of the said timing period, said control means including first means for causing a predetermined drip rate decreasing adjustment, independent in magnitude of said disparity, to said adjustable means when said subsequent drip occurs before the end of the timing period and second means for causing a predetermined drip rate increasing adjustment, independent in magnitude of said disparity, to said adjustable means when said subsequent drip occurs after the end of the timing period.

2. Apparatus as claimed in claim **1**, further comprising a further timer means defining a further period after the end of the said timing period, and means responsive to said further timer means for inhibiting any change in the drip rate if the said subsequent drip occurs within said further period.

3. Apparatus as claimed in claim **1** in which said control means comprises means responsive to the occurrence of the said subsequent drip to provide a control signal, means under the control of the timer to provide a first signal during the timing period and a second signal after the end of the timing period, a first logical AND circuit for producing an output signal in response to the control signal and the said first signal, and a second logical AND circuit for producing an output signal in response to the control signal and the said second signal, and in which the adjustable means includes drive means, means responsive to the output signal from said first AND circuit for feeding always the same predetermined drive signal to said drive means and means responsive to the output signal from said second AND circuit for feeding always the same predetermined drive signal to said drive means.

4. Apparatus as claimed in claim **3** further comprising means under the control of the timer arranged to provide a third signal at times other than during a further period after the end of said timing period, said AND circuits being operative to cause changes in the drip rate only during their reception of the third signal.

5. Apparatus as claimed in claim **3** in which the delivery device includes a flexible tube, said adjustable means includes a clamp on said tube and a motor for driving said clamp, and the control means includes two circuits each triggerable to provide a fixed duration signal to said motor, one of the said two circuits being arranged to be triggered if the said subsequent drip occurs within the timing period and the other circuit is arranged to be triggered if the said subsequent pulse occurs after the end of the said further period.

6. Apparatus as claimed in claim **5** further comprising a further timer means defining a further period after the end of said timing period and means responsive to said further timer means for inhibiting the triggering of said two circuits if said subsequent pulse occurs within said further period.

7. Apparatus as claimed in claim **1** in which means are provided for varying the said timing period.

8. Apparatus as claimed in claim **2**, further comprising means coupled to said timer for varying said timing period and means coupled to said further timer means for varying the said further period.

9. Apparatus as claimed in claim **1** in which the timer comprises a capacitor, a triggerable constant current generator for charging the capacitor and means responsive when the voltage across the capacitor attains a predetermined value.

10. Apparatus as claimed in claim **1** in which a further timer is arranged to be reset and restarted in response to each drip and an alarm under the control of the further timer is operative if the further timer reaches the end of its timing period.

11. Apparatus as claimed in claim **1** in which a diode pump integrator is arranged to be fed with a pulse in response to each drip and an alarm responds to an excessively high integration stored by the diode pump integrator.

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