

[54] PATIENT MOVEMENT MONITORING APPARATUS

[75] Inventor: John Thomas Grant, Guestwick, England
[73] Assignee: Peak Technologies Limited, Isleworth, Middlesex, England
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[58] Field of Search 128/2 R, 2 S, 2 A, 2 N, 128/2.08, DIG. 29; 340/279, 258 A

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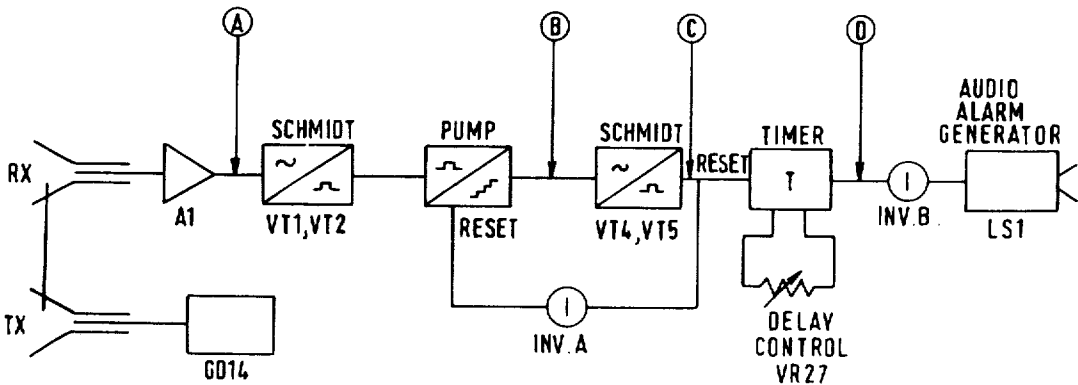
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Primary Examiner—Kyle L. Howell
Attorney, Agent, or Firm—Phillips, Moore, Weissenberger, Lempio & Strabala

[57] ABSTRACT
A system for monitoring cyclic movements, such as respiration of a patient, and indicating when such movement ceases comprises a scanner arranged in use to provide a movement-sensitive field. For patient monitoring this field envelopes at least part of the patient. Circuitry for monitoring variations in the field controls indicator circuitry which provides the indication that movement has ceased. The indicator circuitry provides a signal for each successive group of a predetermined number of movement cycles and responds to the absence of such a signal in a predetermined interval from the preceding signal to provide the indication that movement has ceased. In the case of monitoring respiration, an alarm is given after a predetermined delay from cessation of breathing unless the patient's movements provide signals in the scanner output corresponding to a predetermined number of breathing cycles. Extraneous movements near the patients are unlikely to cause this to happen, so that the system is virtually certain to provide an alarm as soon as possible after cessation of breathing without being inhibited by extraneous movements.

7 Claims, 6 Drawing Figures



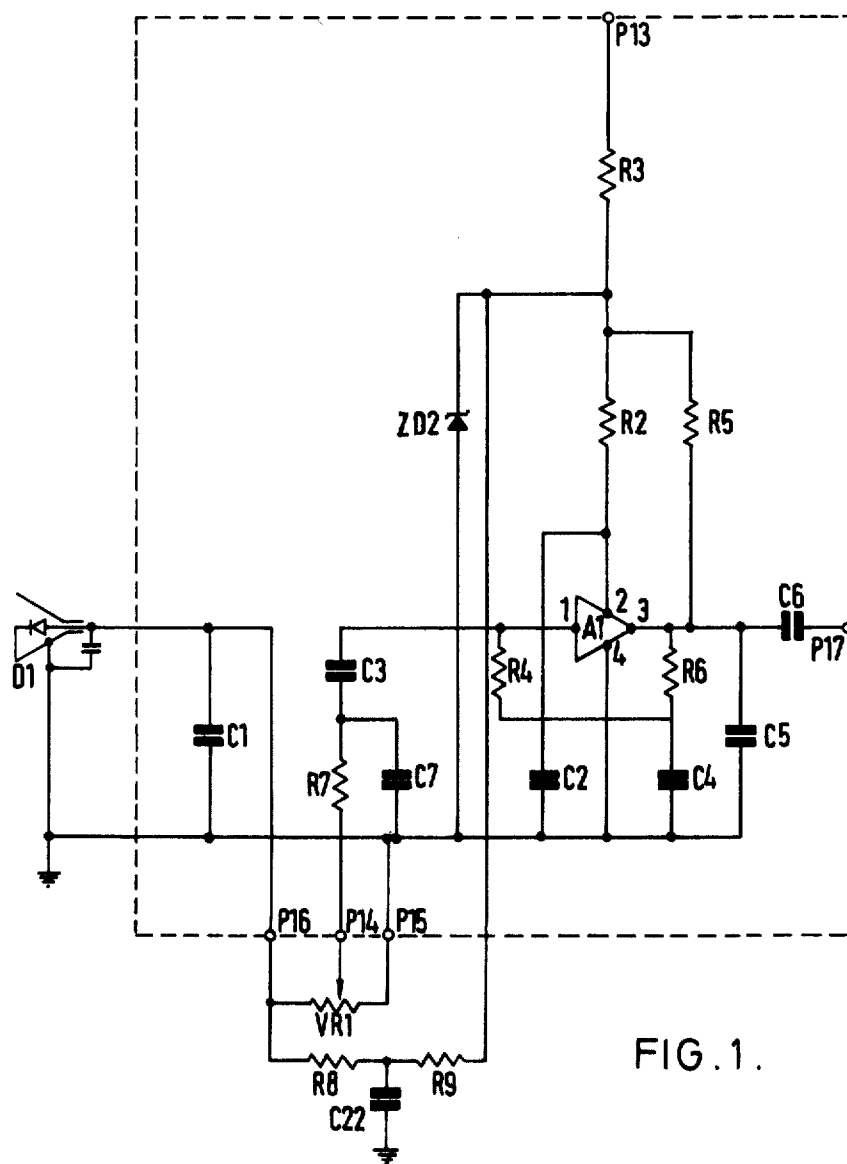


FIG. 1.

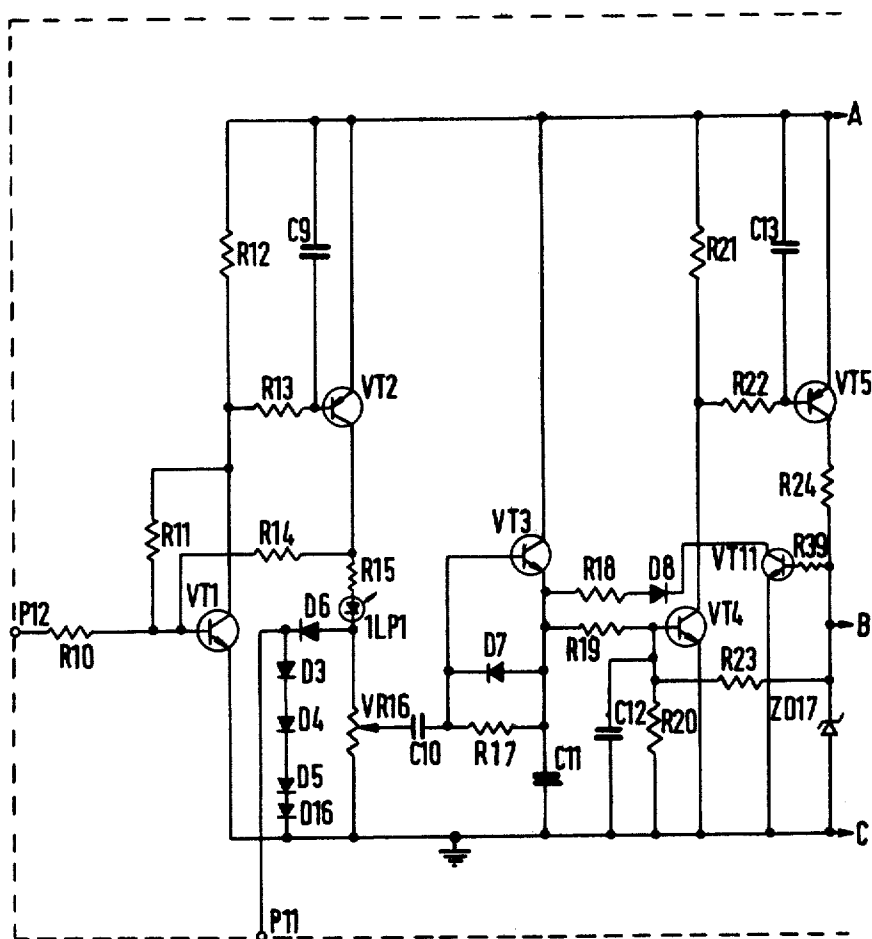


FIG. 2

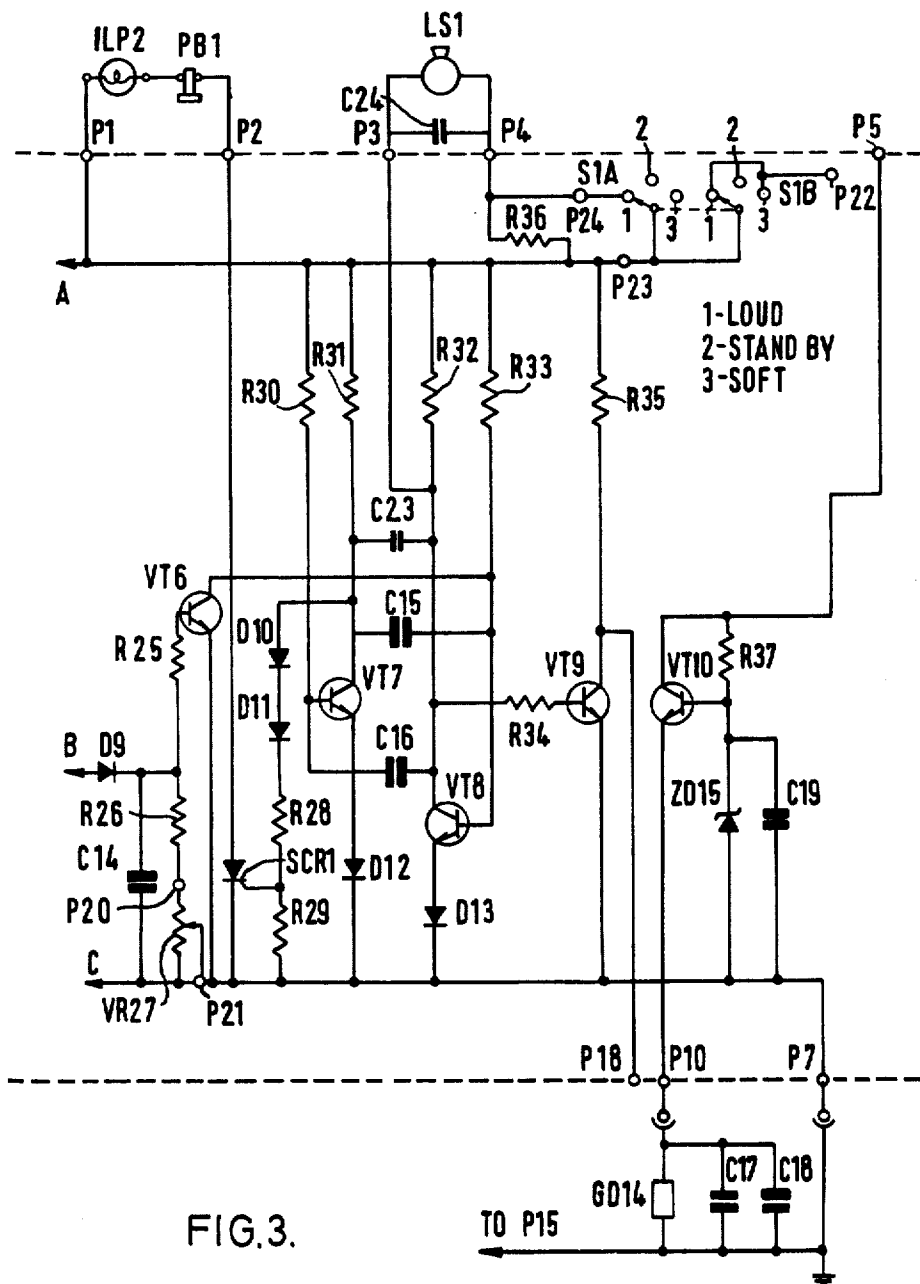
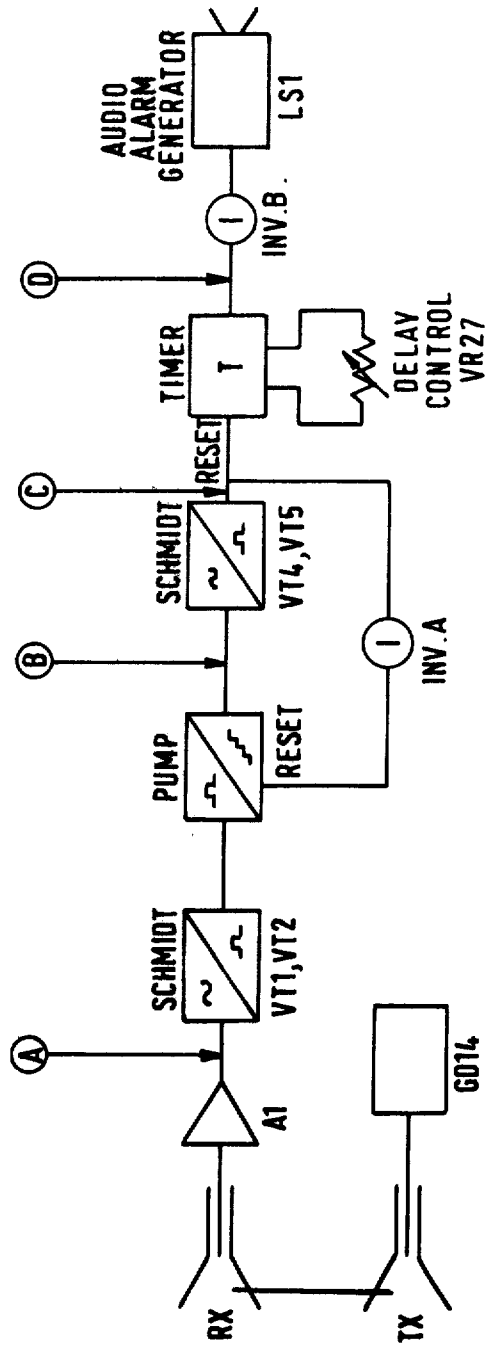
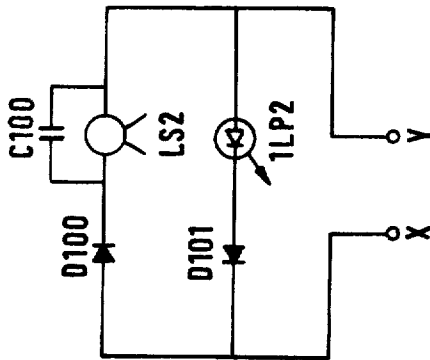


FIG. 4.



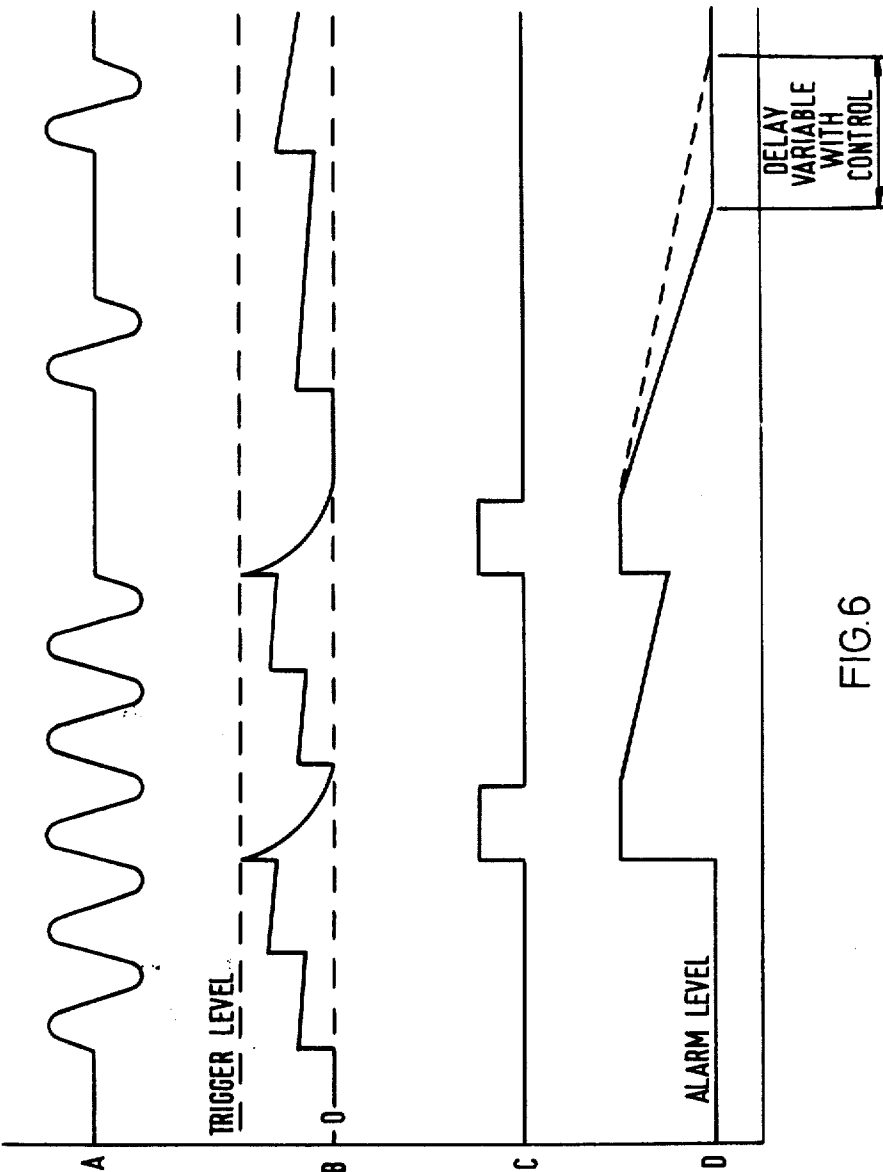


FIG.6

PATIENT MOVEMENT MONITORING APPARATUS

The present invention relates to improvements in the monitoring of patients, and is more particularly concerned with an improvement in the invention of the commonly owned prior co-pending Application No. 225934 filed 14 Feb. 1972 which issued on Mar. 12, 1974 as U.S. Pat. No. 3,796,208 and will hereinafter be referred to as the prior patent.

The prior patent describes a system suitable for monitoring movements of a patient and indicating when the degree of movement is such as to require attention, the system comprising a scanner arranged in use to provide a movement-sensitive field enveloping at least part of the patient, circuitry for monitoring variations in the field, and indicator circuitry controlled by the monitoring circuitry to provide the indication that attention to the patient is required.

The monitor system is particularly, but not exclusively, suitable for use as a respiration monitor or apnea detector, registering the respiration of a patient by means of the movements of the patient's chest wall. Apnea is the cessation of respiration and is a common condition in premature babies. As explained in the prior patent, provided apnea is detected quickly enough, it is generally possible to restimulate respiration.

The system described in the prior patent is made insensitive to movements at frequencies higher than those likely to be encountered in breathing, that is to say of the order of 80 cycles per minute. This lessens the likelihood of the device being activated by movements extraneous to the patient. With this system, it has been found that the presence of persons standing within a foot or two of a baby's cot did not appear to interfere with the operation of the detector, provided that its sensitivity was appropriately regulated.

The system of the prior patent has also been used for monitoring respiration in adults, and it has been found that the presence of staff alongside the bed and movements of patients in adjacent beds have caused no interference in operation.

Nevertheless, it has been found that in some circumstances movements other than those of the patient monitored can produce anomalous operation. This is particularly so when the breathing of a premature baby under intensive care is monitored, through the acrylic or glass top of an incubator. This produces not only an enforced extra distance between the monitor and the patient, and so a larger irradiated area, but also the likelihood of scatter from the incubator top.

The system activates an alarm after a predetermined delay from cessation of breathing. The difficulty experienced is that extraneous movements during this delay period may be interpreted by the monitor system as a normal breathing cycle and may re-set the alarm timer circuitry without the alarm being sounded. The additional delay can have serious consequences for the patient.

The present invention is intended to provide a system in which this disadvantage is substantially eliminated.

In accordance with the present invention a system for monitoring cyclic movements of a patient and indicating when such movement ceases comprises a scanner arranged in use to provide a movement-sensitive field enveloping at least part of the patient, circuitry for

monitoring variations in the field, and indicator circuitry controlled by the monitoring circuitry to provide the indication that movement has ceased, the indicator circuitry providing a signal for each successive group of a predetermined number of movement cycles and responding to the absence of such a signal in a predetermined interval from the preceding signal to provide the indication that movement has ceased.

It will be appreciated that with this system an alarm is given after a predetermined delay from cessation of breathing unless extraneous movements around the patient are such as to provide signals in the scanner output corresponding to the predetermined number of breathing cycles. This is most unlikely to happen, so that the system is virtually certain to provide an alarm as soon as possible after cessation of breathing without being inhibited by extraneous movements.

In the following detailed description, the circuitry of the monitoring system will be described in detail, except where it is very similar to that described in the prior patent. Likewise, the detailed operation of the system will not be described in the present specification, the reader being referred to the prior patent for further details.

The invention will now be described in more detail, by way of example and with reference to the accompanying diagrammatic drawings in which:

FIGS. 1, 2 and 3 are three sections of the circuitry of the monitoring system, being contained in a single unit with the radar unit antennae;

FIG. 4 shows a remote alarm unit for connection to this unit;

FIG. 5 is a block diagram of the system; and

FIG. 6 is a waveform diagram related to FIG. 5.

Referring to FIG. 1, the receiver antenna of the radar unit is associated with a mixer diode D1 whose cathode is connected to the grounded horn antenna and whose anode is connected to ground through electrolytic capacitance C1. The anode of the diode D1 is also connected to a terminal P16 of a printed circuit board on which the majority of the components shown in FIG. 1 are mounted. The opposite ends of a variable resistance VR1 are connected to terminal P16 and a further terminal P15. The variable tap of the resistance VR1 is connected to a terminal P14.

Terminal P14 is connected through the series-connected combination of a resistance R7 and an electrolytic capacitance C3 to the input 1 of an integrated circuit amplifier A1. The junction of resistance R7 and capacitance C3 is connected to ground through an electrolytic capacitance C7. Terminal P15 is also connected to ground. A first power supply terminal 2 of the amplifier A1 is connected to a terminal P13 through the series-connected combination of resistances R2 and R3. It is also connected to ground through an electrolytic capacitance C2. The junction of resistances R2 and R3 is connected to the amplifier output 3 through a resistance R5 and to the cathode of a zener diode ZD2 whose anode is connected to ground. The cathode of the zener diode ZD2 is also connected through the series-connected combination of resistances R8 and R9 to terminal P16. The junction of resistances R8 and R9 is connected to ground through an electrolytic capacitance C22.

The second power supply terminal 4 of the amplifier A1 is connected to ground.

The amplifier output 3 is connected to ground through the series-connected combination of a resistance R6 and an electrolytic capacitance C4. This series-connected combination is shunted by an electrolytic capacitance C5, and the junction of resistance R6 and capacitance C4 is connected to the amplifier input 1 through a resistance R4. The amplifier output 3 is also connected through an electrolytic capacitance C6 to a terminal P17.

FIG. 2 shows part of a second printed circuit board, a terminal P12 on which is connected to terminal P17 of the board shown in FIG. 1.

Terminal P12 is connected through a resistance R10 to the base of a first NPN transistor VT1 whose emitter is connected to ground. The collector of this transistor is connected to the positive rail A through a resistance R12, and to the transistor base through a resistance R11. The collector of transistor VT1 is further connected through a resistance R13 to the base of a first PNP transistor VT2 whose emitter is connected to the positive rail A. The base of this transistor VT2 is connected to the positive rail A through a capacitance C9. Its collector is connected through a resistance R14 to the base of transistor VT1 and through a resistance R15 to the anode of a light-emitting diode ILP1 whose cathode is connected to ground through a preset variable resistance VR16. The cathode of diode ILP1 is connected to the anode of a diode D6 whose cathode is connected to a terminal P11 of the board and is also connected to ground through diodes D3, D4, D5 and D16 connected in series and in the same direction of current flow, the anode of diode D3 being connected to the cathode of diode D6 and the cathode of diode D16 being connected to ground.

The variable tap of the resistance VR16 is connected through a capacitance C10 to the base of a second NPN transistor VT3 whose emitter is connected to ground through an electrolytic capacitance C11. The collector VT3 is connected to the positive rail A.

The emitter VT3 is also connected to the anode of a diode D7 whose cathode is connected to the base VT3. Diode D7 is shunted by a resistance R17.

The emitter of transistor VT3 is connected through a resistance R18 to the anode of a diode D8 whose cathode is connected to the collector of an NPN transistor VT11. The emitter of transistor VT11 is connected to ground.

The emitter of transistor VT3 is also connected through a resistance R19 to the base of a NPN transistor VT4 whose emitter is connected to ground and whose collector is connected to the positive rail A through a resistance R21. The base of transistor VT4 is connected to ground through a resistance R20 shunted by a capacitance C12.

The collector of transistor VT4 is also connected through a resistance R22 to the base of a PNP transistor VT5 whose emitter is connected to the positive rail A. The base VT3 is connected to rail A through a capacitance C13. The collector of transistor VT5 is connected through a resistance R24 to the cathode of a zener diode ZD17 whose anode is connected to ground. The cathode of zener diode ZD17 is connected to the base of transistor VT11 through a resistance R39. It is also connected through a resistance R23 to the base of transistor VT4.

FIG. 3 shows the remainder of the printed circuit board of which part is shown in FIG. 2.

Referring to FIG. 3, the anode of a diode D9 is connected to the cathode of the zener diode ZD17 (FIG. 2), as indicated by the arrows B in FIGS. 2 and 3.

The cathode of diode D9 is connected to ground through an electrolytic capacitance C14 shunted by the series-connected combination of a resistance R26 and a variable resistance VR27 whose variable tap is connected to ground. The cathode of diode D9 is also connected through a resistance R25 to the base of an NPN transistor VT6 whose emitter is connected to ground and whose collector is connected to the positive rail A through a resistance R33. The collector VT6 is also connected to the base of an NPN transistor VT8 whose emitter is connected to the anode of a diode D13 whose cathode is connected to ground. The collector of transistor VT8 is connected to the positive rail A through a resistance R32 and also to a terminal P3. It is further connected through a capacitance C23 to the collector of an NPN transistor VT7 whose collector is connected to the positive rail A through a resistance R31. The base of transistor VT7 is connected to the positive rail A through a resistance R30. The base of this transistor VT7 is also connected through an electrolytic capacitance C16 to the collector of transistor VT8, and the collector is connected to the base of transistor VT8 through an electrolytic capacitance C15. The collector is further connected to the anode of a diode D10 whose cathode is connected to the anode of a diode D11 whose cathode is connected to ground through a series-connected combination of resistances R28 and R29. The junction of resistances R28 and R29 is connected to the gate electrode of a controlled rectifier SCR1 whose cathode is connected to ground and whose anode is connected to a terminal P2.

The collector of transistor VT8 is connected through a resistance R34 to the base of an NPN transistor VT9 whose emitter is connected to ground. The collector of this transistor VT9 is connected to the positive rail A through a resistance R35 and also to a terminal P18.

An NPN transistor VT10 has its emitter connected to a terminal P10 and its collector connected to a terminal P5. The collector is further connected to the base through a resistance R37, the base being connected to the cathode of a zener diode ZD15 whose anode is connected to ground. The zener diode ZD15 is shunted by an electrolytic capacitance C19.

A terminal P4 is connected to the positive rail A through a resistance R36 and also to a first fixed contact 1 of a first section S1A of a two-pole three-position switch. The second and third fixed contacts of switch section S1A are unconnected and the movable contact is connected to the positive rail A, as is the movable contact of the other switch section S1B. Fixed contacts 1 and 3 of switch section S1B are connected together to a terminal P22. The fixed contact 2 of switched section S1B is left unconnected.

Between terminals P3 and P4 is connected an audible alarm LS1, consisting of an oscillator and loudspeaker. The alarm LS1 is shunted by a capacitance C24.

Between terminals P1 and P2 is connected the series-connected combination of an alarm indicator lamp ILP2 and an alarm indicator reset button PB1.

Terminal P10 is connected to one side of the resonant cavity and Gunn diode assembly GD14 of the transmitter aerial. The other terminal of the cavity and Gunn diode are grounded. The cavity and Gunn diode are shunted by capacitances C17 and C18.

Terminal P7 is connected to a common ground point for the circuitry mounted on the boards of FIGS. 2 and 3, terminal P15 in FIG. 1 being also connected to this grounding point.

Terminals P5 and P22 are respectively connected to a smoothed and an unsmoothed power supply (not shown).

By way of example, terminal P5 may be connected to P22 through a low-value resistance the opposite ends of which are connected to ground through respective high-value capacitances. Terminal P22 would be connected through a suitable resistance to the positive terminal of a bridge rectifier, the negative terminal of which would be grounded and the input terminals of which would be connected to respective terminals of the printed circuit board for connection to the secondary winding of a main transformer. A main indicator lamp may be provided, connected in series with a resistance across the primary transformer winding, and the live connection to the transformer primary winding may be fused.

Terminals P11 and P18 are connected to a socket for an external alarm, which will shortly be described with reference to FIG. 4.

Terminals P13 and P5 are connected together. Terminals P17 and P12 are connected together.

Referring to FIG. 4, the external alarm has terminals X and Y for connection to a plug for insertion in the socket connected to terminals P11 and P18. To terminal X are connected the anode of a diode D100 and the cathode of a diode D101. The cathode of diode D100 is connected to terminal Y through an audible alarm LS2, suitably identical to the alarm LS1 of FIG. 3, shunted by a capacitance C100.

The anode of diode D101 is connected to the cathode of a light-emitting diode ILP2 whose anode is connected to terminal Y.

The overall operation of the system will now be described with reference to FIGS. 5 and 6, of which FIG. 5 is a block diagram of the system and FIG. 6 is a waveform diagram related to FIG. 5.

Referring to FIG. 5, the transmitting and receiving antennas, TX and RX respectively are shown coupled to the Gunn diode cavity assembly GD14 and the amplifier A1 respectively. The output of the amplifier A1 is connected to the Schmidt trigger formed by transistors VT1 and VT2, whose output is connected to the pump circuit formed by the transistor VT3 and capacitance C11.

The voltage monitored at point A in FIG. 5 is the output voltage of the amplifier A1, while that monitored at point B is the voltage across the capacitance C11.

The output of the pump circuit is connected to the Schmidt trigger comprising transistors VT4 and VT5, the output voltage of which is monitored at point C. The output of the second Schmidt trigger is also applied through an inverter A, formed by transistor VT11, to the reset input of the pump circuit.

The second Schmidt trigger output is applied to the input of a timer consisting of capacitance C14 and the associated circuitry, the delay control resistance being variable resistance VR27. The voltage at the output of the timer is monitored at point D, and is applied through an inverter B to the audio alarm generator LS1.

The waveforms observed at points A to D are shown in the correspondingly referenced lines in FIG. 6.

The amplifier has a frequency response centered in the region of 1 Hz, having roll-off points at 0.3 Hz and 3 Hz. It has been found that normal extraneous movement in the close vicinity of the monitor produces signals in the frequency range of 5 to 100 Hz, with occasional signals in the 1 to 5 Hz region.

These frequencies are typically caused when a movement relative to the monitor changes direction, so producing a frequency range with a dip in the region of 1 to 5 Hz. This will result in a single output cycle from the first Schmidt trigger.

Normally natural human movement around a patient under observation will produce spurious responses at a rate of some 1 every 5 seconds in the worst case.

Waveform A is the amplifier output typical of normal respiration at a rate of 30 breathes per minute. Respiration at rates of between 10 and 150 breaths per minute will produce the waveform B at the output of the pump circuit.

The second Schmidt trigger will trigger at a predetermined voltage which is reached by successive steps from the pump circuit. By varying the pulse or step height, the number of pulses required to reach the trigger level can be varied, but typically the pulse height is set to allow three pulses before the second Schmidt trigger is fired.

It is thus seen from the left-hand portion of FIG. 6, that during uninterrupted respiration an output pulse is produced by the second Schmidt trigger for every three cycles of the respiration waveform A.

When the second Schmidt trigger is fired the voltage at the output of the pump circuit is discharged to near ground potential by means of the inverter A. A further three pulses can then be accepted before the trigger is re-fired.

The right-hand portion of waveform B shows a cessation of respiration after some 5 breath cycles. In this period two spurious respiration pulses are shown, but it will be observed from waveform B that these do not result in firing the second Schmidt trigger.

Waveform D shows how the timer output is reset on the occurrence of each output pulse from the second Schmidt trigger. On cessation of breathing, however, when firing of the Schmidt trigger ceases, the timer output voltage drops to zero, the time for this being adjustable by means of the delay control VR27.

When the timer output reaches zero, the inverter B (transistor VT6) no longer inhibits operation of the audible alarm LS1, which provides the appropriate alarm signal.

Referring again to FIGS. 1 to 3, the diode D1 produces a signal corresponding to movements of the chest cavity and diaphragm of the patient. The amplifier A1 produces a substantially sine-wave output within the frequency range 0.3 Hz to 3 Hz.

The amplifier output is passed to a Schmidt trigger consisting of transistors VT1 and VT2 providing drive for the light-emitting diodes ILP1 and ILP2. Drive is also provided to capacitance C10 which couples the pulsed amplifier output to the pump transistor VT3, the capacitance C11 forming a reservoir.

Transistors VT4 and VT5 form a second Schmidt trigger with a wide input differential. When the charge on capacitance C11 reaches a predetermined level, after three pulses from the pumped transistor, for example, the Schmidt trigger changes state to provide drive to the timer reservoir capacitance C14 and tran-

sistor VT11. This discharges capacitance C11 to a low level whereupon the Schmidt trigger returns to its original "off" state.

If resistance VR16 is set to give a pulse height which results in three cycles before Schmidt trigger is fired, it follows that capacitance C14 would be re-charged every three pulses. Resistance VR27 controls the discharge rate of capacitance C14 and therefore varies the time delay between cessation of breathing and the provision of an alarm.

Transistor VT6 is a clamp transistor which inhibits free-running of the multivibrator formed by transistors VT7 and VT8. This multivibrator has a free-running rate in the region of 50 to 100 cycles per minute and is used to drive the audible alarm LS1.

The controlled rectifier SCR1 drives a visual alarm indicator and is triggered by the first cycle of the multivibrator. Transistor VT9 forms a buffer amplifier which is used to drive the external audible alarm unit (FIG. 4).

Transistor VT10 and the associated components provide a smoothed DC power supply to the Gunn diode cavity GD14.

The switch S1 provides a standby facility by removing power from the alarm circuit while maintaining power to the microwave transmitter and receiver circuits, so avoiding delay due to the charging of capacitances C1, C3 and C4, which have long time constants due to the frequency response of the system.

During normal operation clamp transistor VT6 holds the base of transistor VT8 at ground potential, so that transistor VT9 will be fully conducting and its collector, and therefore one output terminal of the external alarm socket, will be at ground potential. The other socket terminal will have a voltage on it varying between zero and some 2.8 volts, at the patient respiration rate. If this is applied in the correct sense to the external alarm unit (FIG. 4), the light-emitting diode ILP2 can glow. When an alarm condition exists transistor VT9 will have a voltage on it varying between zero and 13 volts. This will cause a reverse potential to appear at the remote alarm unit, thus activating the audible alarm LS2 and extinguishing the light-emitting diode ILP2.

I claim:

1. Movement monitoring apparatus comprising:

- a. microwave radar means providing a limited movement-sensitive field of microwave radiation;
- b. monitor circuit means monitoring disturbances of said field and providing at its output a pulsed signal indicative of the degree of field disturbance;
- c. resettable aggregating circuit means coupled to the output of said monitor circuit means to aggregate said pulsed signal to provide at its output a signal voltage the level of which is indicative of said degree of field disturbance;
- d. threshold circuit means defining a predetermined threshold voltage and coupled to the output of said aggregating circuit means to receive said signal voltage;
- e. trigger circuit means to said threshold circuit

means to be activated thereby when said signal voltage reaches said predetermined threshold voltage;

- f. resetting circuit means coupled to the output of said trigger circuit means and to said aggregating circuit means to re-set said aggregating circuit means when said trigger circuit means is activated;
- g. resettable delay circuit means coupled to the output of said trigger circuit means and providing a predetermined delay between the appearance at its input of an input signal caused by activation of said trigger circuit means and the appearance at its output of a pre-determined output signal level, activation of said trigger circuit means re-setting said delay circuit means to re-start said pre-determined delay; and

h. alarm circuit means connected to the output of said delay circuit means and activated by said pre-determined output signal level thereof,

said predetermined threshold voltage and said predetermined output signal level of said delay circuit means being so selected in relation to the frequency of said pulsed output signal of said monitor circuit means that said delay circuit means is repeatedly re-set by the output of said trigger circuit means so long as there is a predetermined degree of movement in the movement-sensitive field and is not re-set after the degree of movement falls below said predetermined degree until there is generated a sufficient number of cycles of said pulsed output signal of said monitor circuit means to provide at the output of said aggregating circuit means a signal voltage sufficient to cause activation of said trigger circuit means.

2. A system as set forth in claim 1, in which said aggregating circuit means includes a reservoir capacitance charged via a transistor.

3. A system as set forth in claim 1, in which said trigger circuit means is a Schmidt trigger.

4. A system as set forth in claim 1, in which said resetting circuit means includes an inverter.

5. A system as set forth in claim 1, in which said alarm circuit means is connected to the output of said delay circuit means through an inverter which inhibits operation of said alarm circuit means while the output signal level of said delay circuit means exceeds said predetermined value.

6. A system as set forth in claim 1, in which said radar means provides at its output Doppler frequency signal indicative of movements in the movement-sensitive field and in which said monitor circuit means includes a frequency-selective amplifier for said Doppler frequency signals, having a narrow pass-band centered on a frequency corresponding to a particular class of movement to be monitored, and further trigger circuit means connected to the output of said amplifier and providing at its output said pulsed output signal of said monitor circuit means.

7. A system as set forth in claim 6, in which said further trigger circuit means is a Schmidt trigger.

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