

- [54] **PIEZOELECTRIC TRAFFIC COUNTER SWITCH AND ASSOCIATED PULSE GENERATOR CIRCUIT**
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- [58] Field of Search .... **340/38 R; 310/8.1, 8.7**

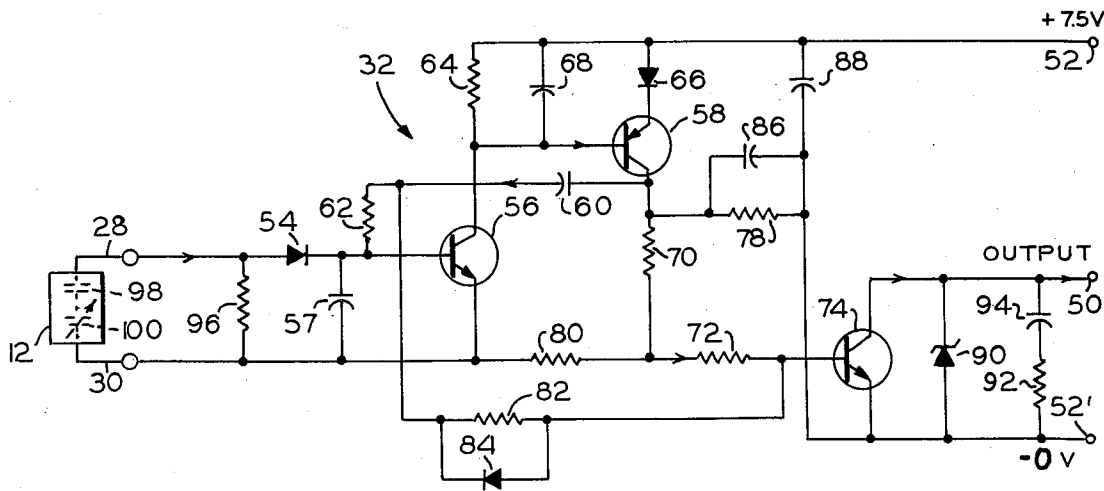
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- UNITED STATES PATENTS**
- 3,699,398 10/1972 Newmeyer ..... 340/38 R

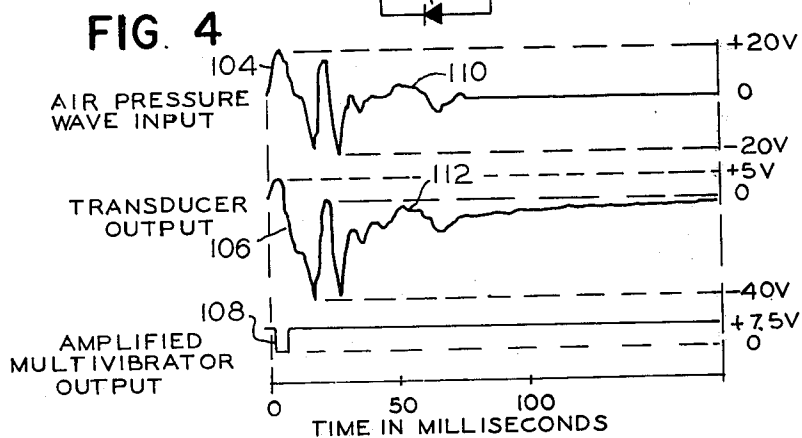
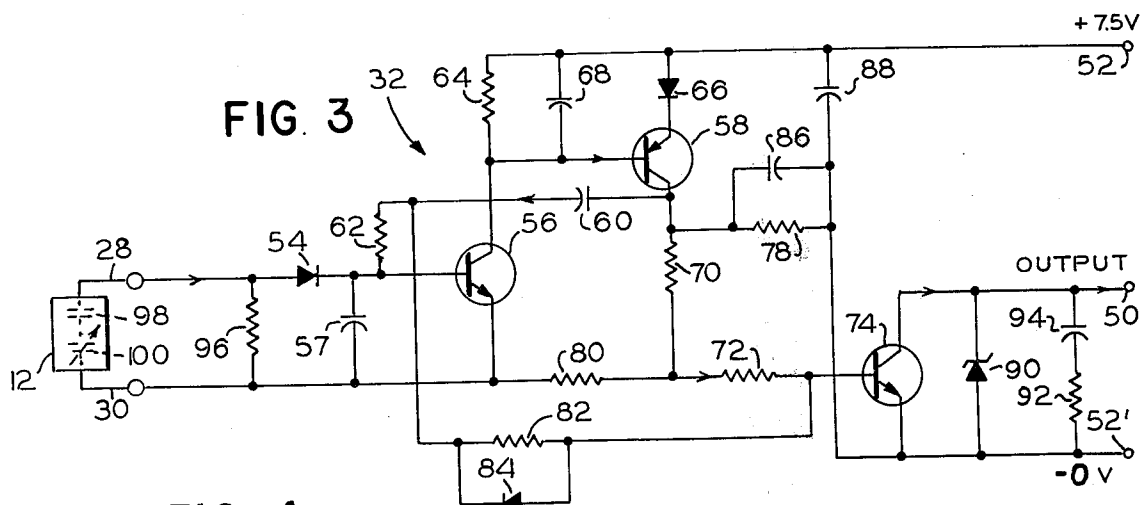
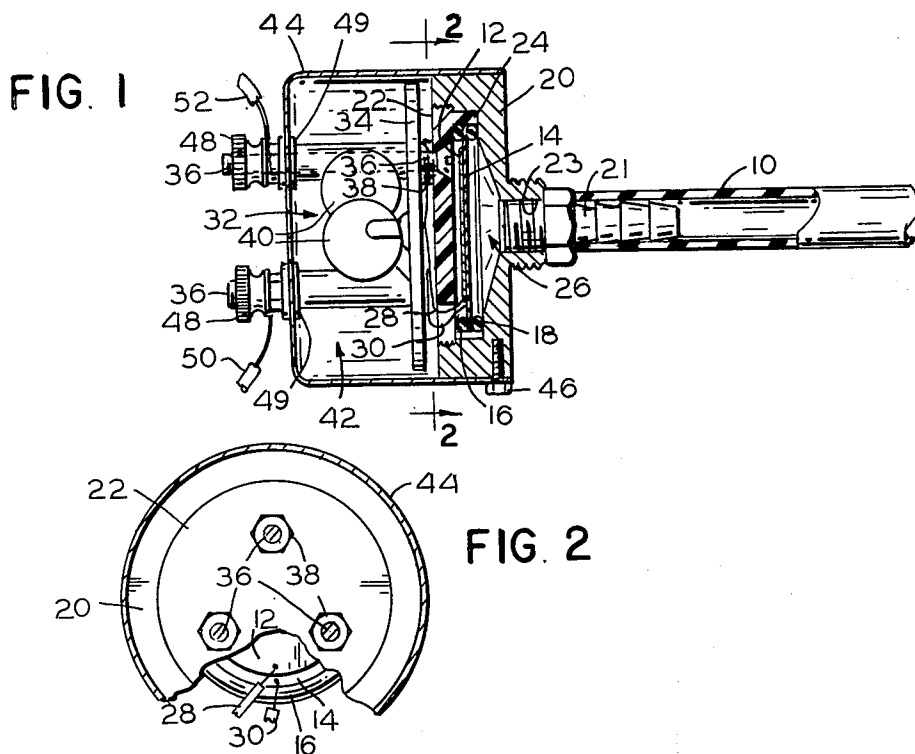
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- [57] **ABSTRACT**
- A traffic counter switch and associated pulse genera-

tor circuit is described which uses a piezoelectric transducer to convert air pressure waves produced in a pneumatic tube by vehicles crossing such tube, into corresponding electrical pulses which are supplied to a traffic counter. The piezoelectric transducer output pulses trigger a monostable multivibrator in the pulse generator circuit without amplification of such transducer pulses. The transducer and associated pulse generator circuit are mounted within a common housing which is separated into two chambers by a diaphragm supporting the transducer, such circuit being provided in a chamber separate and hermetically sealed from the chamber containing the transducer. Most of the false triggerings of the multivibrator by reflections of the air pressure wave from the end of the pneumatic tube, are prevented by connecting the equivalent circuit capacitance of such transducer to a high discharge resistance. As a result the RC time constant of the transducer capacitance is sufficiently long to prevent such reflections from producing transducer output pulses which trigger the multivibrator.

11 Claims, 4 Drawing Figures





## PIEZOELECTRIC TRAFFIC COUNTER SWITCH AND ASSOCIATED PULSE GENERATOR CIRCUIT

### BACKGROUND OF THE INVENTION

The subject matter of the present invention relates generally to vehicle sensor apparatus using a piezoelectric transducer coupled to a fluid filled tube, and in particular to a piezoelectric transducer switch and associated pulse generator circuit for producing an electrical output pulse in response to the receipt of an air pressure wave generated within a pneumatic tube provided on the surface of a road by a vehicle crossing such tube. The sensor apparatus of the present invention is particularly useful as a vehicle traffic counter.

Previously, traffic counter switches have included an electro-magnetic transducer, as shown in U.S. Pat. No. 3,699,398 of Newmeyer, granted Oct. 17, 1972, and a carbon microphone, as shown in U.S. Pat. No. 3,105,952 of Kidder, granted Oct. 1, 1963. In addition, vehicle detectors have employed piezoelectric transducers permanently mounted in the roadway, as shown in U.S. Pat. No. 3,346,842 of Dixon, granted Oct. 10, 1967. Also, piezoelectric transducers have even been connected to tubes buried in the ground for perimeter intrusion alarm systems, as shown in U.S. Pat. No. 3,438,021 of Nelkin et al, granted Apr. 8, 1969. However because of the expense and complicated nature of such prior apparatus, most traffic counter switches in use today are simple mechanical switches which are actuated by movement of a diaphragm coupled to the pneumatic road tube.

The piezoelectric traffic counter switch apparatus of the present invention is simpler, less expensive, more trouble free, and of longer useful lifetime than prior art traffic counter switches. This is due in part to the use of an electrical pulse generator circuit including a monostable multivibrator which is triggered directly by the output signal of the piezoelectric transducer without amplification of the transducer output signal. The multivibrator produces output pulses of substantially the same amplitude and duration regardless of the transducer signal trigger waveform, and such output pulses are applied to the traffic counter.

In addition, the pulse generator circuit and the transducer are mounted in a common housing which is divided into two chambers by the diaphragm on which the transducer is mounted so that the electrical circuit is positioned in one chamber separate and sealed from the other chamber containing the transducer mounting diaphragm which communicates with the pneumatic tube. As a result, maintenance of the switch is virtually eliminated because dust and other foreign material are not transmitted from the road tube into the chamber containing the electrical circuit. Also there are no moving switch contacts to wear out.

The transducer diaphragm is mechanically isolated from the housing in the apparatus of the invention so that it is not effected by expansion and contraction of the housing due to temperature changes in the atmosphere. In addition, the piezoelectric transducer is connected to a high electrical resistance so that the RC time constant of the equivalent circuit capacitance of such transducer is sufficiently long to prevent air pressure reflections within the pneumatic tube from producing transducer pulses which trigger the monostable multivibrator and provide false output pulses to the traffic counter.

Previous attempts to avoid the effect of air pressure reflections in the pneumatic tube include using a bleed-hole at the end of the tube, or providing an additional coiled section of tube at the end which acts as a delay line for such reflections. However, these techniques generally have not been satisfactory because, among other things, the bleed-hole may become clogged with dirt and the length of the delay line portion of the road tube varies with the width of the road on which such tube is used.

The traffic counter switch apparatus of the present invention will detect the presence of vehicular traffic over a large range of speeds, for example, from about 5 miles per hour to 80 miles per hour, and over a large range of vehicle weights from small compact automobiles to large trucks. In addition to changes in traffic speeds, the traffic counter switch apparatus of the present invention automatically compensates for variations in lengths of the pneumatic tube, up to 60 feet.

### SUMMARY OF INVENTION

It is, therefore, one object of the present invention to provide an improved vehicle sensing apparatus of simple and inexpensive construction, of long useful lifetime, and maintenance free operation, using a piezoelectric transducer coupled to a fluid filled tube.

Another object of the present invention is to provide such a vehicle sensor apparatus in which the output of the piezoelectric transducer is connected to a monostable multivibrator in a pulse generator circuit in order to trigger such multivibrator directly by the transducer output signals without amplification, such multivibrator producing output pulses of predetermined amplitude and duration when triggered.

A further object of the invention is to provide such a vehicle sensor apparatus of high accuracy in which the RC time constant for discharging the equivalent circuit capacitance of the piezoelectric transducer is sufficient to prevent most reflections of the fluid pressure wave produced in the tube from causing the transducer to generate output signals which trigger the multivibrator and produce false output pulses.

An additional object of the present invention is to provide such a sensor apparatus in which the pulse generator circuit is mounted in a housing compartment which is sealed from a separate compartment coupled to the road tube and containing the diaphragm on which the transducer is mounted.

Still another object of the present invention is to provide such a vehicle sensor apparatus in which the diaphragm mounting the piezoelectric transducer is mechanically isolated from the housing so that the transducer is unaffected by changes in atmospheric temperature and the pulse generator circuit is self-compensating for temperature changes over a wide range of temperatures.

A still further object of the present invention is to provide such a vehicle sensor apparatus whose output pulses are transmitted to a traffic counter to detect the presence of vehicles over a wide range of vehicle speeds and weights without the need for calibration adjustments.

### BRIEF DESCRIPTION OF DRAWINGS

Other objects and advantages of the present invention will be apparent from the following detailed description of a preferred embodiment thereof and from the attached drawings of which:

FIG. 1 is a side view of one embodiment of the vehicle sensor apparatus of the present invention with parts broken away for clarity;

FIG. 2 is a vertical section view taken along the line 2—2 of FIG. 1;

FIG. 3 is a schematic diagram of the pulse generator circuit connected to the piezoelectric transducer used in the sensor apparatus of FIG. 1; and

FIG. 4 is a schematic diagram of electrical signal waveforms produced in the circuit of FIG. 3.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIGS. 1 and 2, one embodiment of the vehicle sensor apparatus of the present invention includes a hollow road tube 10 of rubber or other resilient synthetic plastic material which is filled with air or other fluid. Thus the road tube is adapted to be positioned on the upper surface of the road so that vehicles contact such tube and produce fluid pressure waves within the tube. The road tube 10 has one end coupled to a piezoelectric transducer 12 fixedly attached to a flexible metal diaphragm 14. The metal diaphragm is mounted for bending movement between a pair of circular rubber O rings 16 and 18 which are clamped between a metal base member 20 and a threaded support plate 22 of synthetic plastic insulating material which screws into a threaded opening in such base member. The pneumatic tube 10 slips over a fitting 21 threaded into another opening 23 in the base member 20. The support plate 22 includes an annular flange 24 which surrounds the two rubber O rings 16 and 18 and limits the expansion of such rings when they are compressed. Flange 24 also serves as a stop to determine the distance that the support plate 22 can be screwed into the base member 20 in order to provide such O rings with sufficient compression to maintain a pneumatic seal between the diaphragm 14 and members 20 and 22. This forms a first chamber 26 which communicates with the pneumatic tube 10 so that air pressure waves produced within such tube are communicated through such chamber to the diaphragm 14 to cause such diaphragm to flex, thereby bending the piezoelectric transducer and producing a corresponding electrical output signal at output terminals 28 and 30 of the transducer.

The outputs 28 and 30 of the transducer are connected as the inputs of a pulse generator circuit 32 which is mounted on an etched circuit board 34. The circuit board is attached to the support plate 22 by bolts 36 and separated from such support plate by spacer nuts 38. The circuit board 34 is of conventional construction consisting of an insulator plate having metal strip lead connections provided on one side thereof to which the transducer output terminals 28 and 30 are connected. The circuit components including capacitors 40 are mounted on the other side of the circuit board from the lead strips and electrically connected through holes in the circuit board to the lead strips on the opposite sides thereof.

The pulse generator of circuit 32 and associated circuit board 34 are mounted in a second chamber 42

formed between the base member 20 and a cup-shaped metal cover member 44 attached to the base member by small metal screws 46 to provide the sensor housing. The second chamber 42 is separated from the first chamber 26 within the housing by the metal diaphragm 14. As noted previously, the rubber O rings 16 and 18 provide a pneumatic seal around the outer edge of the diaphragm 14 so that the second chamber 42 containing the pulse generator circuit is pneumatically sealed from the first chamber 26 to prevent dust and other material from entering such second chamber through the road tube 10.

Three electrical terminals 48 are provided on the exterior of the housing cover 44, such terminals being threaded on the ends of the bolts 36. The bolts pass through insulating grommets 49 which insulate them from the housing cover 44. One of the bolts 36 is connected to the output signal lead 50 of the pulse generator, and the other two bolts are connected to supply voltage leads 52 for connecting the circuit to positive and negative sources of D.C. supply voltage. It should be noted that the bolts 36 are insulated from each other by the insulator support plate 22. Also, such bolts are each individually connected to electrical leads on the etched circuit board 34 so that they function as electrical connectors from the circuit to the output lead 50 and the supply voltage lead 52.

The pulse generator circuit 32 is shown in FIG. 3, and includes the piezoelectric transducer 12 whose upper output lead 28 is connected through a diode 54 to the base of an NPN transistor 56 which serves as the input stage of a monostable multivibrator. Thus, positive transducer output pulses produced on output 28 when a vehicle crosses the road tube 10 are transmitted through the diode 54 to trigger the monostable multivibrator and cause it to generate a rectangular output pulse of predetermined amplitude and pulse width at the output terminal 50 of the pulse generator. This output pulse is applied to a traffic counter connected to output terminal 50 which counts the output pulses and relates the total number of pulses to the number of vehicles crossing the road tube 10. One such traffic counter is shown in pending U.S. Pat. application Ser. No. 421,826, filed Dec. 5, 1973, by H. G. Lee and the present inventor.

A high frequency bypass capacitor 57 of 0.001 microfarad is connected between the base and emitter of the input transistor. The collector of transistor 56 is connected to the base of a PNP transistor 58 functioning as the output stage of the multivibrator. Transistor 58 has its collector connected to the base of transistor 56 through a positive feedback impedance including a coupling capacitor 60 of about 0.047 microfarad and an isolation resistor 62 of about 82 kilohms. The collector of transistor 56 is connected through a load resistor 64 of 100 kilohms to a source of positive D.C. supply voltage of about +7.5 volts at terminal 52. The emitter of transistor 58 is also connected to terminal 52 through diode 66. An A.C. bypass capacitor 68 of 0.01 microfarad is connected from the base of transistor 58 to the supply terminal 52 in parallel with load resistor 64. The collector of transistor 58 is connected through a pair of series connected load resistors 70 and 72 of 390 ohms and 150 ohms, respectively, to the base of an NPN output amplifier transistor 74. Transistor 74 is connected as a common emitter or phase inverter amplifier. The collector of transistor 74 is connected to

the output terminal 50 of the pulse generator circuit, while the emitter of such transistor is connected to a source of negative D.C. supply voltage of zero volts at supply terminal 52'. The negative supply terminal 52' is also connected through a resistor 78 of 22 kilohms to the collector of transistor 58. The emitter of transistor 56 is connected through a current limiting resistor 80 of 3.3 kilohms to the junction of resistors 70 and 72.

All of the transistors 56, 58 and 74 are quiescently biased nonconducting. A positive pulse produced on the output 28 of the transducer 12 is transmitted through the coupling diode 54 to the base of transistor 56 and switches such transistor to a conducting state, thereby triggering the monostable multivibrator. Transistor 56 inverts the positive transducer signal and applies a negative pulse to the base of transistor 58 switching it to a conducting state and producing a positive pulse on its collector. This positive pulse switches transistor 74 conducting and produces a negative output pulse on output terminal 50. The positive pulse is also transmitted as a positive feedback signal through coupling capacitor 60 back to the base of transistor 56 which rapidly drives such transistor into a saturated conducting condition. The coupling capacitor 60 charges through a timing resistor 82 of 120 kilohms toward the negative D.C. supply voltage provided on the base of the conducting transistor 74. Thus the timing resistor 82 determines the charging time for the coupling capacitor 60 and therefore the duration or pulse width of the output pulse produced by the monostable multivibrator and applied to the base of the output amplifier transistor 74. Once the coupling capacitor 60 has charged sufficiently negative, the input transistor 56 is rendered nonconducting which in turn renders the second transistor 58 nonconducting. This causes the coupling capacitor 60 to discharge through a shorting diode 84 connected in parallel with the timing resistor 82 so that it effectively short circuits such timing resistor during discharge of the capacitor 60 and thereby reduces such discharge time. Once the capacitor discharges transistor 74 switches back to a nonconducting state terminating the output pulse produced on output terminal 50. Thus the duration of such output pulse is determined by the charging and discharging time of the capacitor 60 in the multivibrator. It should be noted that the total discharge resistance also includes resistors 70 and 72 which are of a much lower value, however, than the timing resistor 82. The monostable multivibrator also includes a high frequency A.C. bypass capacitor 86 of about 0.001 microfarad connected in parallel with resistor 78.

A larger filter capacitor 88 of 1.0 microfarads is connected between the positive and negative D.C. supply terminals 52 and 52' to isolate the circuit from any A.C. noise signal such as that produced by the motor of the traffic counter connected to output 50. The power amplifier output transistor 74 is provided with a Zener diode 90 connected between its emitter and collector to limit the voltage across such transistor to a predetermined value which will not damage the transistor. In addition, a series load impedance including a resistor 92 of 100 ohms and a capacitor 94 of 0.01 microfarads is connected between the collector and emitter of transistor 74 across the Zener diode.

An input shunt resistance 96 of 3.9 megohms is connected between the output terminals 28 and 30 of the piezoelectric transducer 12 so that the equivalent cir-

cuit capacitance of such transducer, represented by a fixed capacitance 98 of 0.025 microfarad and a variable voltage source 100, has a long RC time constant of approximately 97.5 milliseconds. Thus, the RC time constant of the equivalent transducer capacitance 98 and shunt resistor 96 is sufficient to provide a long discharge time for such capacitance so that air pressure wave reflections produced in the pneumatic tube 10 do not cause the piezoelectric transducer 12 to trigger the monostable multivibrator. These air pressure wave reflections and other spurious air pressure signals are often produced by reflections of the air pressure wave from the end of the road tube 12.

It should be noted that the isolation resistor 62 enables the use of a large timing capacitor 60 and a small timing resistor 82 to provide a multivibrator output pulse of high current. The isolation resistor isolates the output of the transducer 12 from the loading that such a large timing capacitor and small timing resistor would otherwise cause.

As shown in FIG. 4, when an automobile passes over the road tube 10, it produces an air pressure wave 104 within such road tube. The pressure wave was measured by a reference sensor having a 10 megohm load connected at the end of a forty foot long road tube with the automobile traveling at a speed of about 25 miles per hour. The resulting air pressure wave signal 104 varies between a positive peak of +20 volts and a negative peak of about -20 volts over a time interval of about 50 milliseconds. This pressure wave is the input to the piezoelectric transducer 12 in the circuit of FIG. 3 which produces a corresponding transducer output signal 106 at the junction of diode 54 and resistor 96. The transducer output signal varies between a peak positive voltage of about +5 volts and a peak negative voltage of about -40 volts. The positive voltage portion of the transducer output signal 106 triggers the monostable multivibrator 56 and 58 and causes it to produce a positive output pulse of uniform height and width. This positive output pulse is inverted and amplified by the amplifier transistor 74 to produce a negative amplified multivibrator output pulse 108 of -7.5 volts amplitude at output terminal 50. As shown in FIG. 4, the output pulse 108 is produced when the transducer output signal 106 exceeds a positive voltage triggering level of the multivibrator of about 1.5 volts at the beginning of such transducer output signal.

The air pressure waveform 104 includes a positive peak portion 110 which corresponds to a pressure signal reflection in the road tube. This pressure reflection 110 produces a corresponding transducer signal portion shown by positive going reflection portion 112 in the transducer output signal 106 at a time of about 55 milliseconds from the start of such output signal. As shown in FIG. 4, the positive going reflection 112 actually has a peak value of about -4 volts and does not exceed the positive trigger voltage level of the multivibrator so that it does not trigger such multivibrator. It should be noted that the multivibrator is in a reverted condition and could be triggered by a positive voltage reflection signal portion since the amplified multivibrator output pulse 108 terminates in less than 10 milliseconds. This prevention of triggering of the multivibrator by the reflection signal portion 112 is caused by the fact that the RC time constant of the transducer 12 and shunt resistor 96 is about 97.5 milliseconds, so that the reflection occurs long before the end of such time con-

stant. This means that the transducer is still charged to a negative voltage on its upper terminal at the time the reflection signal occurs so that such reflection signal never reaches the positive voltage necessary for triggering. Thus, while the reflection signal portion 112 has an amplitude of about +10 volts, it begins at a voltage of about -14 volts and therefore its peak voltage is only about -4 volts, which of course is not sufficient to trigger the multivibrator. In this manner, air pressure wave reflections produced within the road tube are prevented from causing the transducer to trigger the monostable multivibrator and produce false output pulses at output terminal 50. As a result, the multivibrator may be triggered directly by the output signal of the transducer without amplification of such output signal because the trigger level of the multivibrator can be set low without false triggering.

It will be obvious to those having ordinary skill in the art that many changes may be made in the details of the above-described preferred embodiment of the present invention. Therefore, the scope of the present invention should only be determined by the following claims.

I claim:

1. A vehicle sensor apparatus in which the improvement comprises:

a fluid tube means for producing a pressure wave within said tube when a vehicle contacts such tube;  
a piezoelectric transducer means coupled to an open end of said tube for producing an electrical output pulse in response to receipt of said pressure wave; and

an electronic switch circuit including a monostable multivibrator having its input connected to said transducer so that said multivibrator is triggered directly by the transducer output pulse without amplification to produce a multivibrator output pulse.

2. A sensor apparatus in accordance with claim 1 in which the switching circuit is contained within a housing also containing said transducer means, said switching circuit being electrically isolated from any D.C. ground.

3. A sensor apparatus in accordance with claim 2 in which the transducer includes piezoelectric material supported on a diaphragm mounted by a mounting means within the housing and separating the housing into two chambers, one chamber containing the electrical switching circuit and pneumatically sealed from the other chamber which is connected to the open end of said tube.

4. A sensor apparatus in accordance with claim 3 in

which the mounting means includes a pair of rings of resilient insulating material provided on opposite sides of a metal diaphragm forming one electrode of the transducer.

5. A sensor apparatus in accordance with claim 1 in which the monostable multivibrator includes an input transistor having its output connected to the input of an output transistor, and the transducer output signal is applied to the input electrode of said input transistor to trigger the multivibrator and produce the multivibrator output pulse on the output electrode of said output transistor.

6. A sensor apparatus in accordance with claim 5 in which the input electrode of said input transistor is connected through a diode to the transducer.

7. A sensor apparatus in accordance with claim 6 in which there is a shunt resistor connected across the output of the transducer and a shunt capacitor connected across the input of the input transistor, and the diode is connected between said shunt resistor and said shunt capacitor.

8. A sensor apparatus in accordance with claim 5 in which a timing capacitor is connected between the output electrode of said output transistor and the input electrode of said input transistor, a timing resistor is connected between the timing capacitor and a D.C. voltage terminal for charging said timing capacitor through said timing resistor, and a diode connected across the timing resistor for discharging the timing capacitor.

9. A sensor apparatus in accordance with claim 1 in which the piezoelectric transducer is connected to a resistance of a high value so that the RC time constant of the capacitance of said transducer is greater than the period of the monostable multivibrator and is sufficient to prevent spurious pressure waves within the tube from causing the transducer to produce false output pulses which trigger the multivibrator.

10. A sensor apparatus in accordance with claim 9 in which the resistance is a shunt resistor connected across the output of the transducer, a shunt capacitor is connected across the input of the multivibrator, and a diode is connected between the shunt resistor and the shunt capacitor.

11. A sensor apparatus in accordance with claim 5 which also includes an isolation resistor connected between the input electrode of said input transistor and the common connection terminal of a timing capacitor and a timing resistor in said multivibrator.

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