Fuel Tank Level Sensor with Digital Output

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Introduction

The conventional method of monitoring fuel level in automotive applications consists of a float/rheostat assembly whereby liquid height is converted via a rotating wiper arm to an electrical output signal. A novel alternative method is presented, using a "digital ultrasound" method in which a vertical array detects liquid presence or absence in discrete steps. The transducer employs internal low-power logic circuitry, and outputs count and synchronisation pulses to a remote interface. It is envisaged that this device will ultimately communicate directly with a microprocessor, but with minimal additional circuitry, an analog output voltage proportional to fuel level may be produced. In addition, this method offers the possibility of density determination and profiling (via pulse transit time), compensation for non-uniform tank geometry (by varying segment spacing in the array) and self-check capability (via a fixed reference channel). The design uses no "moving parts", and accuracy can be preset during the design phase. Power requirements for the transducer are less than standard sender requirements.

Outline Description

At the heart of the device lies a pair of printed-circuit boards (pcbs), vertically oriented, and spaced apart. Opposing (front) faces are clad with piezoelectric polymer material, while the rear faces carry associated electronics, encapsulated in resin. One pcb carries the segmented transmitter array, while the other comprises a single rectangular sensor covering the full sensing height.

Each transmitter segment is pulsed sequentially. Liquid couples an ultrasonic signal from that transmitter segment through to the large receiver, while air blocks the signal totally. Thus the last segment to generate an output from the receiver indicates the height of the liquid column between the pcbs.

The unique properties of the piezoelectric polymer allow a single, fast, low voltage pulse to be used as the transmitter drive signal, and close spacing of the pcbs to be possible. Using the pcbs to carry the signal electrodes eliminates the need for multiple interconnection to the piezopolymer.

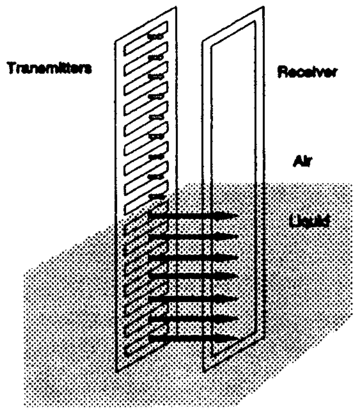

Figure 1 Transducer Schematic

Mechanical Design

The transducer consists essentially of two rectangular circuit boards, mounted facing each other, with long axes vertical. They are spaced apart at a fixed distance, and liquid is allowed to rise and fall in the cavity between them. The front (inward) faces of the boards are clad with piezo film. The rear faces carry transmitter fire/detect logic, and receiver amplifier circuitry.

When inserted into a tube or tubular extrusion, the cavity behind each board (component side) is filled with encapsulant (e.g. epoxy resin) to prevent direct contact between the active electronics and the medium. The ends of the tube are blanked off with plates. The lower plate is fitted with an inlet hole, and the upper plate or tube end similarly equipped with an air bleed orifice. The diameter of these holes determines the fill time constant of the device, and thus the level of damping of liquid height fluctuations due to "slosh".

Electro-acoustic Design

The piezopolymer used in the device generates a change in thickness in response to an applied electric field (in transmit mode) and, conversely, develops an electrical field in the thickness direction due to incident pressure (in receive mode).

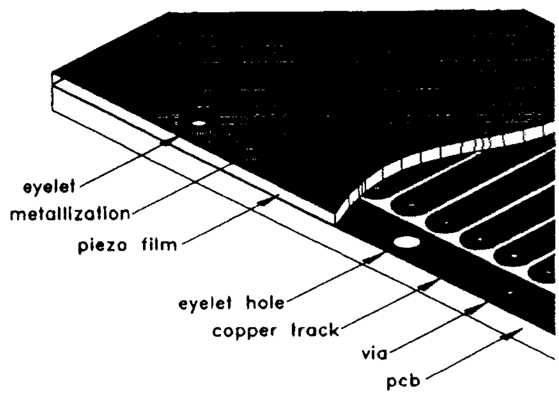

Figure 2 Construction detail

While the acoustic properties of the pcb may not be ideal as a backing layer, the benefit from ease of construction far outweighs any adverse signal effects. In practice, for instance, some acoustic energy is radiated "backwards"into the pcb, and reflects off the rear pcb surface. The received signal generated by a clean incident fast pulse shows an obvious echo arriving some 1.5 µsec after the main signal, due to the pcb.

The outstanding bandwidth capabilities offered by piezopolymers allow the use of a simple rectangular pulse of 5 volt amplitude as the drive signal, with a typical pulse width of 200 nsec.

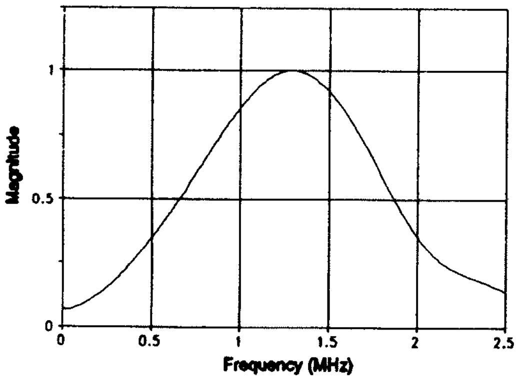

Figure 3 Typical bandwidth of piezopolymer in Tx/Rx mode

Response amplitude has been plotted as a function of liquid temperature, and a gradient of about +0.5%/°C found. Thus for an automotive application covering from -40° to +80°C, we can expect a change in received signal level of -30% to +30% about the 20°C value, or approximately +/- 3 dB. The transition in signal level from liquid just arriving at the lower edge of a transmitter array segment to just fully covering that segment is in the order of 30 dB, and so the net effect of full-range temperature swing is simply a fractional shift in the vertical location of the switching point.

The full transition in signal level between air and liquid is theoretically infinite, since there can be no arrival of signal through air at the same time as through the same distance in liquid (by virtue of the great difference in speeds of sound). Also, the attenuation of ultrasound in air at the frequencies used is very high. In practice, the limit in signal to noise ratio is determined by the receiver system electronic noise. A value of better than 70 dB is practical. This gives excellent margin in the setting of the pulse detect threshhold.

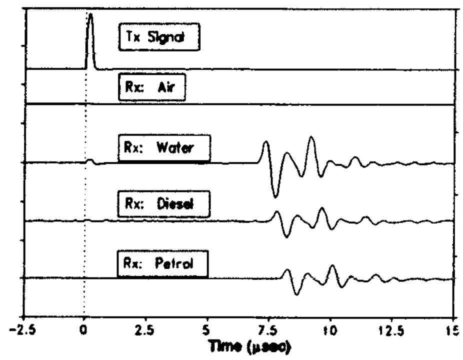

Figure 4 Receiver waveforms

Electronic Design

For experimental purposes, the electronic system is split into two parts: the transducer, and a remote interface and display box. The transducer is entirely self-contained, and requires no input other than power and ground. The interface accepts digital pulses on three lines, and converts the digital liquid level into any other desired output form - typically an analog voltage.

It is practical to arrange an output which would emulate the varying resistance of a float/rheostat assembly. For other applications, a currentloop output may be required, or a serial data link for communication to a PC.

Transmitter signals are sent from high-speed CMOS multiplexer chips (standard CMOS being unable to supply sufficiently fast edges for the pulse). The receiver amplifier is based on a discrete transistor design, offering extremely high gain and bandwidth at very low cost.

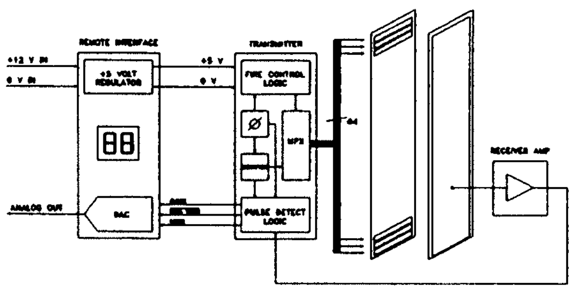

Figure 5 Electronic functional diagram

The transducer consumes approximately 10 mA from a 5 V supply rail, giving a power dissipation of 50 mW. This compares favourably with conventional float/rheostat devices, which can dissipate up to 300 mW. The maximum stored energy in the transducer is about 4 μJ.

With the present experimental series of transducers, the only system element vital to transducer function not to be incorporated internally is the voltage regulation which is presently located within the remote interface unit. A

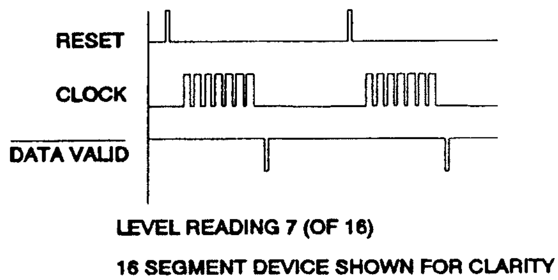

Figure 6 Digital output signals

standard automotive-grade regulator is used, which allows full transducer operation to be gauanteed for supply rails down to 6 V. In practice, the function of the device has been preserved at supply voltages of 3.2 V.

Sensor Performance

Using a sensor with 64 segments in a uniform vertical array, a resolution of 1/64 or 1.56% of range is possible. Measured data shows linearity (output voltage versus liquid depth within tank) of better than 0.45%, or better than 1/3 LSB (see Fig 7).

Future Refinements

The time-of-flight of the ultrasonic pulse can be measured to a high degree of accuracy due to the broad acoustic bandwidth of the piezopolymer, even over a short transit distance. This enables

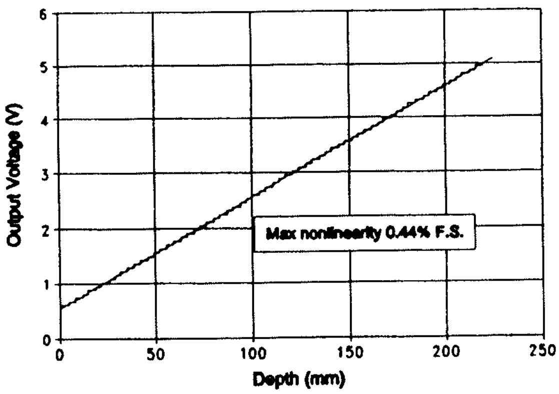

Figure 7 Transducer linearity

liquids of different density to be discriminated, on a segment-to-segment basis. For example, a layer of water lying at the bottom of a fuel tank would yield a difference of some 16% in transit time (relative to unleaded gasoline).

Applications which require the transducer to self-test have been addressed using a solid coupling material covering half the surface of each segment. This causes one pulse to be received from every segment, irrespective of whether liquid is present or not. Because the transit time through the solid is shorter than through liquid, the second pulse (if detected) arrives separated in time. Thus every segment can be checked, even in an empty tank.

Digital linearization of non-uniform height/volume tanks has been tested, as well as segment spacing adjustment (suitable, for instance, for cylindrical tanks lying horizontally).

Conclusions

A new concept in liquid level measurement has been presented, which allows solid-state sensors to be devised which communicate digital information. These transducers appear suitable for a wide range of applications, with particular relevance to the automotive industry on grounds of reliability and accuracy, together with the ability to discriminate fuel density. As more microelectronics become incorporated within the dashboard, the digital output format may appear increasingly attractive.

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