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Study of an IR Defusing Surface of a Float Used as Non-Contact Level Sensor

[1] Sudipta Chakraborty, [2] Nirupama Mandal, [3] Satish Chandra Bera
[1, 2] Department of Electronics, ISM, Dhanbad, India
[3] Instrumentation Engineering Section, Department of Applied Physics, University of Calcutta, 92, A.P.C. Road, Kolkata 700009, India
[1] Tel.: 09432951471
E-mail: sudipta_25@rediffmail.com, scbera_cal52@rediffmail.com, nirupama_cal@rediffmail.com

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Abstract: Float is a very simple sensing element for measurement of liquid level in a storage tank. The float movement is converted into electrical or mechanical signal for indication and transmission of liquid level. The conversional mechanical or electro mechanical technique used for this conversion may suffer form error due to loss of movement in the mechanical linkages. In the present paper a simple non-contact technique has been developed by using infrared light reflected from the defusing surface of a float. The intensity of this reflected light changes with change of level. This principle has been utilized to design a level sensor. The theoretical equations that govern the sensor operation have been derived and have been experimentally verified. The experimental results are reported in the paper. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Liquid level measurement, Diffused reflection of infrared light, Inverse square law, Non contact technique, Float.

1. Introduction

Measurement of Liquid level in a storage tank is very much important in any process industry. The measurement technique may be broadly classified as contact type and non-contact type. In contact type techniques, liquid properties like buoyancy, pressure at a depth, a dielectric constant of a liquid, electrical conductivity, thermal conductivity etc. are utilized to develop liquid level sensor and transducer. Hence there exist a large variety of industrially accepted contact type liquid level sensors such as float type, displacer type, pressure sensing type, differential pressure sensing type, capacitance probe type, partially immersed resistance wire probe type etc. They have the disadvantages that their Characteristic properties with respect to liquid level may change due to the physical or chemical reaction between the liquid and the sensor material. Hence their maintenance cost increases along with limitation of life period. This difficulties are not observed in non-contact type level sensors like ultrasonic type, absorption type, non-contact capacitance type etc. but they are comparatively costly and require various environmental and experimental precautions during the measurement. In ultrasonic level measurement technique, the time interval between instant of transmission of wave from the transmitter and the instant of receiving the reflected wave from the liquid surface is measured. But this measurement technique involves complicated circuit and is generally very costly compared to the other level sensors. X-ray absorption type non-contact technique of level measurement suffers form radiation hazards.

Capacitances type level sensor may be of both contact and non contact types [1-4]. The conventional non contact capacitance type transducer measures the capacitance between liquid surface and a fixed metallic plate above the liquid surface using air as a dielectric medium. An improved form of this transducer for a conductive liquid has been developed by S. C. Bera, *et al*. [13]. A characteristic of a contact type capacitive transducer have been studied by R. Ferran, *et al.* [14]. In recent times some works on infrared [5] related techniques on measurement of distance, and other parameters are being reported by different groups of workers. S. Yingfeng, *et al.* [6] have developed a low cost IR reflective sensor for position measurement. An IR range finder system has been developed by A. Rakshit, *et al*. [7] by sensing reflected IR energy from an object. P. Zappi, *et al.* [8] have utilized IR sensor in Motion detection and distance technique by using reflected energy from teargases. A. Tar, *et al.* [9] have developed a low cost distances proximity measurement technique by using an array of LED photo diode payer for detection of object outline and surface trace. J. W. Youg, *et al.* [10] have utilized low cost infrared transmitter and receiver pair to detect the direction, distance or other parameter of a target. The infrared guidance technique has been utilized by X. Jian-Zhong, *et al.* [11] to estimate a large distance of a target. V. M. Srivastava, *et al.* [12] have studied the data transmission technique by using variation in intensity of light emitted by IR led at deferent logic level. P. M. Novotny, *et al.* [15] have studded the application of infrared sensor in accurate measurement of distance.

The float is a very simple liquid level sensor widely used in industry. The float movement is generally measured by mechanical linkage arrangement where measurement error may be produced due friction by wear and tear effect as well as dust particle deposition effect of the mechanical linkage. Hence design of float type level sensor without any mechanical linkage becomes very much advantageous in level measurement if we use infrared light reflected from float surface. The reflected infrared light signal from a defusing surface is a advantageous over that reflected from a plain surface due to the fact that IR transmitter's virtual image point and the IR receiver need not to be placed face to face during defuse reflection and almost normal reflection from the defusing surface can be captured by the receiver.

In the present paper a defusing surface has been developed from a corrugate tin plate coated with silver. This defusing plate is fixed on a float placed inside a level sensing tube with infrared transmitter and receiver fixed on the top of the tube. The tube is connected with a storage tank. The dimension of the tube and float are so selected that the tube acts as a guide for the float. The infrared transmitting diode is supplied from an oscillator at 32 kHz and the reflected light from the defusing surface of the float is received by an infrared sensitive diode. The average output voltage of the receiver circuit has been found almost to follow the inverse square law of propagation of light from the defusing surface. Thus output is nonlinearly dependent on level. The level transducer designed in this way has been experimentally tested and the experimental results are presented in the paper.

2. Method of Approach

Let us consider a float inside a uniform cylindrical tube acting as level sensing tube. This tube is attached with a liquid storage tank as shown in Fig. 1. The float is in the form of a uniform hollow cylinder with its outside diameter slightly less then the internal diameter of the level sensing tube.

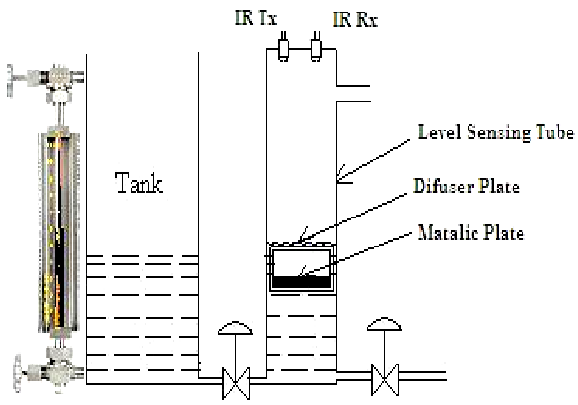

Fig. 1. Proposed level sensing tube.

The inside surface of the level sensing tube is polished and black. It acts as almost a frictionless guide tube for the upward and downward movement of the float with the change of level in the storage tank. The float is so designed that the major part of its height is immersed in the liquid. A corrugated tin plate coated with silver is fixed on the top surface of the float by means of araldite. The top cover plate of the level sensing tube consists on a pair of infrared transmitter and receiver diodes placed inside two central holes of the cover plate so that light emitted form the transmitter is incident on the defusing silver surface of the float and after reflection from the defusing surface it is received by the receiver infrared sensing diode. Since the silver surface is non-uniform so defused reflection of IR light occurs from the silver surface. This reflected light may be assumed to have almost uniform intensity in all directions. So when the reflected infrared beam reaches the receiver diode its intensity on the diode surface may be assumed to follow inverse square law of propagation of light.

Let the intensity of light emitted from the transmitter diode be I_r and its distance from the silver surface is 'D'. Now the reflected light may be assumed to be transmitted from the virtual image of the transmitter diode having the same intensity I_r as the transmitter. Again the transmitter and receiver diodes are placed very much closed to each other so that the distance between the receiver diode and virtual image of the transmitter diode may be assumed to be $2D$. Hence from the inverse square law, the intensity of light at the receiver diode will be given by, $I_r \alpha 1/(2D)^2$ or

$$I_r=K_1/D^2, \tag{1}$$

where K_1 is the constant of proportionality.

Now let the height of the tube from datum level is H. Hence for level h, the distance between silver surface and the transmitter diode is given by,

$$D=H-h-d, \tag{2}$$

where d is the height of the float above the liquid surface.

Thus, from (1) and (2) we have,

$$I_r=\frac{K_1}{(H-h-d)^2} \tag{3}$$

Now to reduce the effect of noise in transmitter diode as well as to increase the sensitivity of receiver diode the chopper or flash type IR transmitter is used as shown in Fig. 2, where D_2 represents the IR transmitter diode operated by IC-555 based oscillator circuit.

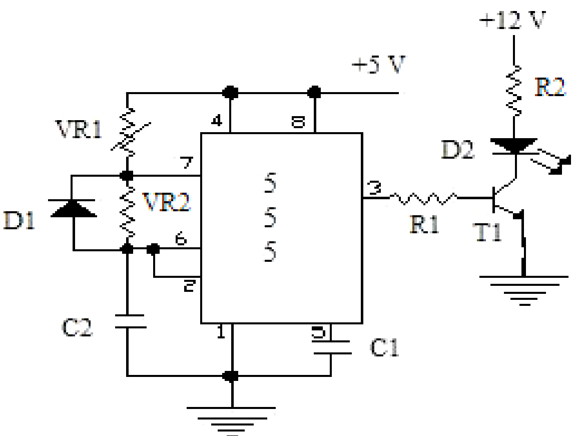

Fig. 2. Proposed IR transmitter circuit.

The light reflected form the defusing plate of the float is received by IR sensitive detector or receiver diode D_3 as shown in Fig. 3. At the receiver diode, the chopping frequency is eliminated by using RC filter so that the output across the RC filter is directly proportional to the average value of the intensity of light (I_r) received by the receiver diode, which in term is nonlinearly related with the liquid level in storage tank. Thus transmitter and receiver IR diode circuit act as level transducer and the output (V_0) of the transducer across RC filter may be given by, $V_o \alpha I$, or

$$V_0=K_2I_r, \tag{4}$$

where K_2 is the constant.

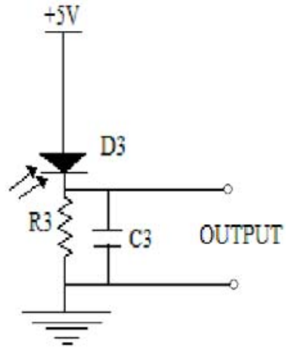

Fig. 3. Proposed IR receiver circuit.

From Equations (3) and (4) we have,

$$V_0=\frac{K_1K_2}{(H-d-h)^2}$$

or

$$V_0=\frac{K}{(H-d-h)^2}, \tag{5}$$

where

$$K=K_1K_2,$$

or

$$\frac{1}{\sqrt{V_0}}=\frac{H-d-h}{\sqrt{k}} \tag{6}$$

Thus transducer output is nonlinearly related with level 'h' as shown in Equation (5) and inverse square root of transducer output is linearly related with liquid level 'h' as shown in Equation (6). This output signal of the transducer after amplification with a signal conditioner circuit can be linearized by using piece wise linearization technique with the help of a microprocessor or microcontroller based software program or by using signal processing technique in Lab View environment or by using a solid state linearization circuit.

3. Design

The proposed sensor consists of level sensing tube made of PVC materiel of internal diameter slightly greater than the outside diameter of float. The float is in the form of a closed cylinder with a metallic plate inside it so that about 5/6 of its height may be immersed in the liquid inside the level sensing tube. The mass of this piece of metal inside the float is so selected that the total mass of the whole float may be equal to the mass of water (or any other liquid) of volume equal to 5/6th the whole volume of the float. A circular corrugated tin plate coated with silver of diameter equal to the diameter of the float is fixed with the top surface by using araldite. The corrugated plate acts as the defusing surface for infrared. The top surface of the level sensing tube is enclosed by a top cover plate consisting of infrared transmitter and receiver LED's fixed in two holes near the central region with their surfaces pointing towards the float. The top cover plate of the level sensing tube also consists of PCB of IR transmitter and receiver circuits. The level sensing tube thus designed is connected with the main storage tank with a one inch connector tube made of stainless steel.

The IR transmitter circuit shown in Fig. 2, is designed so that chopped IR light is emitted by IR diode operated by IC-555 based oscillator circuit at 32 kHz at 50 % duty cycle by proper selection of the oscillator parameters (V_{R_1} =0 kΩ, R_1=1 kΩ, V_{R_2} =22.5 kΩ, R_2=1 kΩ, C_1=0.1 µF, C_2=0.001 µF). The Receiver IR diode circuit shown in Fig. 3 is designed so that 32 kHz signal is bypassed through capacitor C3 with R3 acting as a load (R_3=1 kΩ, C_3=220 µF) and the output voltage (V_0) across C_3 is directly proportional to the intensity of IR light received by IR receiver diode (D_3) from the uneven silver surface of the float. This output is then converted into 1-5 Volt dc signal by a suitable signal conditioner circuit. The output of the signal conditioner circuit is nonlinearly related with level. So this output signal is linearized with the help of a microcontroller based software program. The block Diagram of the whole measuring circuit is shown in Fig. 4.

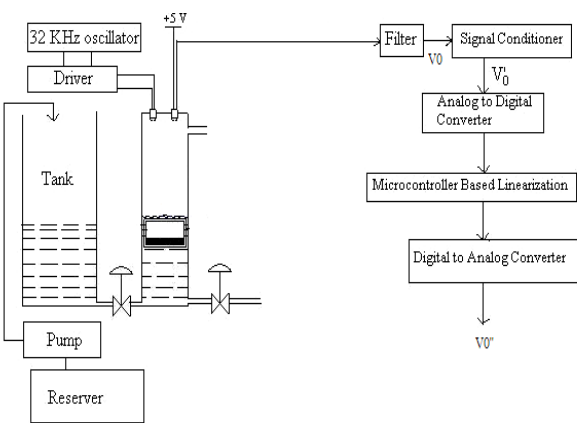

Fig. 4. Block diagram proposed level measuring circuit.

4. Experiment

The experiment is performed in two steps with the experimental setup as shown in Fig. 4. The actual level was measured from gage glass attached with the tank. In the first step, the static characteristic of proposed level sensor was determined by increasing the level of storage tank in steps by opening the inlet valve (V_1) and closing outlet valve (V_2) of the storage tank. In etch step, the receiver circuit output across filter capacitor was measured by a four and half digit digital multi-meter (DIGITEK DT 930F) under steady state condition. The static characteristic curve of the level transducer was drawn by plotting receiver circuit output (V_0) against level in both increasing and decreasing modes. The experimental graphs for three increasing and three decreasing modes are shown in Fig. 5. The standard deviation curve of these data is shown in Fig. 6.

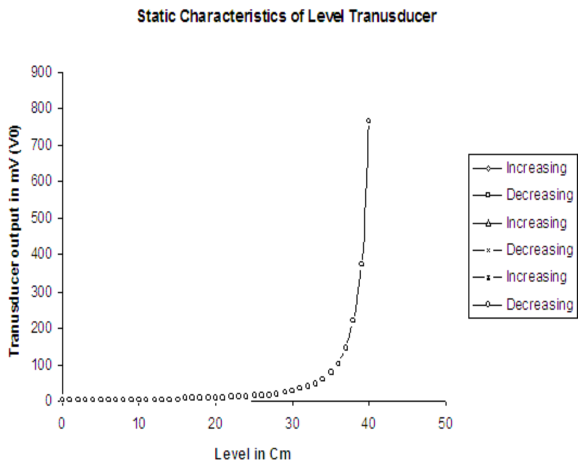

Fig. 5. Static characteristic curve of proposed level transducer.

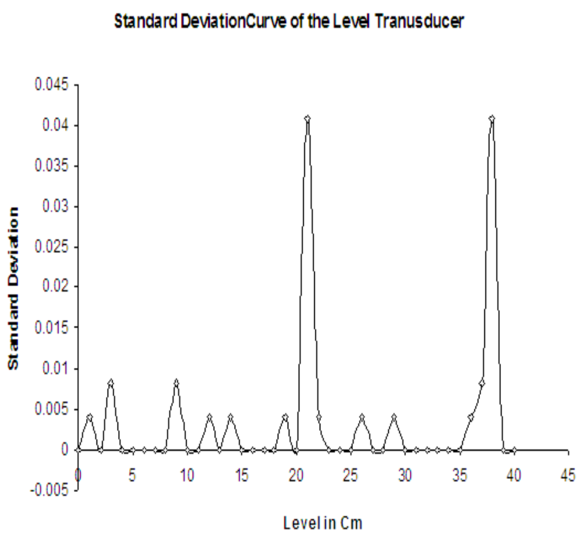

Fig. 6. Standard deviation curve of the proposed level transducer.

From above data, inverse of square root of the average transducer output $\left(\dfrac{1}{\sqrt{V_{0_{Avg.}}}}\right)$ was plotted against level and a straight line curve was obtained as shown in Fig. 7. The percentage deviation from ideal linearity of this curve is shown in Fig. 8.

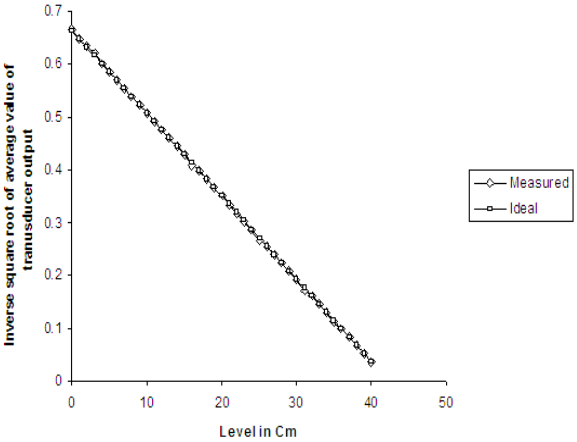

Fig. 7. Inverse square root of average value of level transducer output.

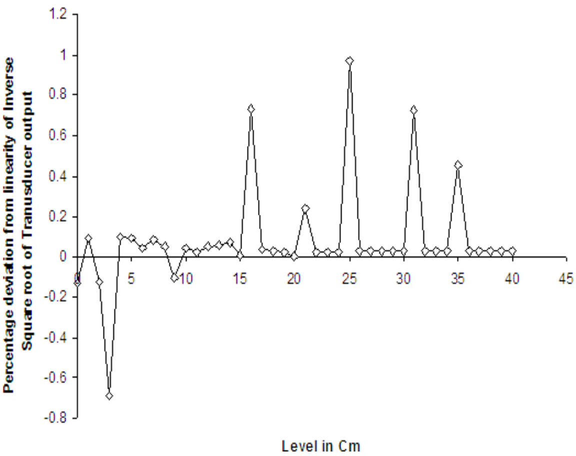

Fig. 8. Percentage deviation from linearity of inverse square root of transducer output.

In the second part of the experiment the static characteristic curve of the signal conditioner circuit of the proposed level measuring system was determined by connecting the output of the IR receiver circuit with the signal conditioner circuit. The liquid level in storage tank was now increased in steps and at each step output of the signal conditioner output was measured by the above digital voltmeter in both increasing and decreasing modes. The static characteristic curves of the signal conditioner circuit for three increasing and three decreasing modes are shown in Fig. 9 and the corresponding standard deviation curve is shown in Fig. 10.

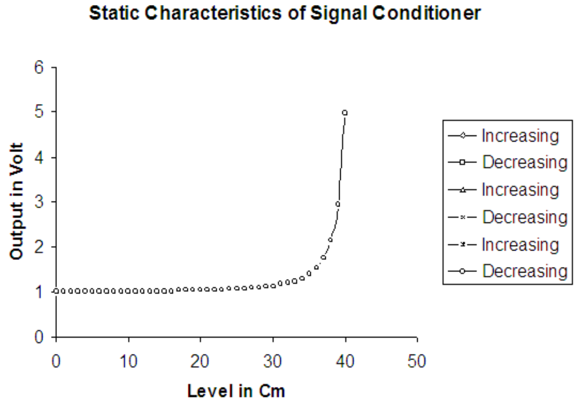

Fig. 9. Static characteristics curve of the signal conditioner circuit of the proposed level sensor.

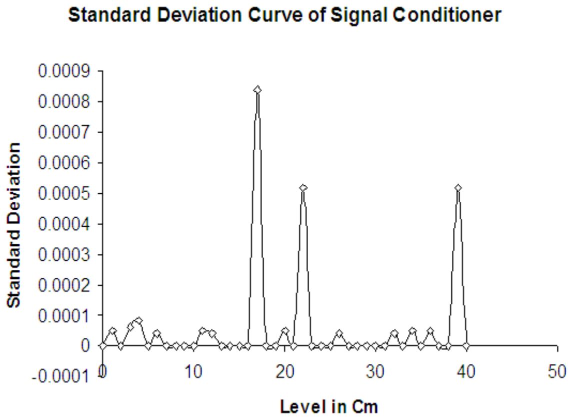

Fig. 10. Standard deviation curve for the measured data of the signal conditioner circuit of the proposed level sensor in there increasing and there decreasing modes.

In the next step of the experimental work, the microcontroller based linearization of the whole level measuring circuit was made. The output of the signal conditioner circuit was sent to the microcontroller input port through ADC and other peripheral devices. Level in storage tank was increased in steps and at etch step, the microcontroller output in engineering unit (millimeter) was recorded. The calibration curve of the whole level measuring circuit was then drawn by plotting observed level against actual level measured from gauge glass as shown in Fig. 11.

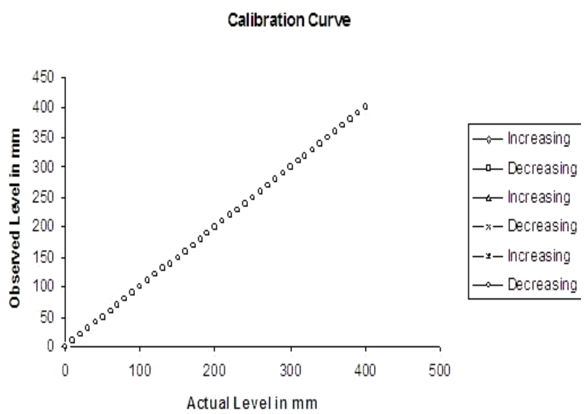

Fig. 11. Calibration curve of the microcontroller based level measuring system.

5. Discussions

The Transducer characteristic as shown in Fig. 5 appears to follow the theoretical Equation (4). The standard deviation curve as shown in Fig. 6 indicates a good repeatability of the transducer. The experimental curve obtained by plotting inverse square root of transducer output against level as shown in Fig. 7 is found to be quite linear and appears to flow the theoretical Equation (6) with percentage deviation from ideal linearity with in tolerable limit as shown in Fig 8. The static characteristic curve of the signal conditioner circuit as shown in Fig. 9 appears to follow the transducer characteristic and it is found to have a good repeatability as shown in the standard deviation curve in Fig. 10.

The nonlinearity of the signal conditioner characteristic is eliminated by using piece-wise linearization technique in software program of microcontroller and the LCD display in engineering unit (mm) is obtained. The calibration curves of the display unit in both increasing and decreasing modes are found to be identical as shown in Fig. 11. The technique is very simple and requires little hardware circuit compared to the transit time technique of ultrasonic type level measurement. Hence it may be assumed to be less costly.

The measurement technique does not suffer form error due to any electromagnetic interference effect since intensity of light wave is used as the sensor parameter. Again the float material is selected to be made of plastic. Hence the temperature of the liquid has little effect on the defusing property of diffuser plate of the float. The inside surface of the level sensing tube is made polished and its internal diameter is made slightly greater than the external diameter of the float so that there is little friction between float and tube and the tube acts as a guide for free movement of float. In the present work black plastic tube has been used to avoid any interference from outside sources of light.

In the present paper a detailed study of the transducer has been made and a very simple arrangement of IR transmitter and receiver system has been designed to measure the liquid level by using float as the primary sensor. The main advantage of the technique is the elimination of error due to friction effect of mechanical linkages in the conventional float based level transducer. The principle of float is the well known Archimedes principle and should not have any novelty in its theoretical analysis and technical design of the float. The special feature in the proposed design is the utilization of silver surface as the IR diffuser to obtain almost uniform intensity of reflected light for any position of the float. The intensity of defused light may depend on the type of the material of the reflecting surface and type of non–uniformity of the surface. In the present design corrugated surface has been used and almost uniform intensity of defused light has been observed for different positions of the receiver diode for a particular level.

Each of characteristic curves shown in Figs. 5, 9 and 11 is plotted for experimental data obtained in three increasing and three decreasing modes. But these data are so close that when they are plotted in the same graph paper by using Microsoft Excel, the graphs superimpose with one another to resemble a single graph. This indicates very good repeatability of the experimental data.

The proposed technique may suffer from reduction in long term stability due to tilting of float and staining of IR transmitter and receiver along with reflecting surface. However, this effect is applicable in every conventional float based measurement of liquid level, where serious measurement errors due to friction of mechanical linkages are sometimes observed in industry. The present technique is a non contact technique and does not suffer form such errors. Like all electronic instruments long term stability of the present technique may be less then that of conventional float based system but by proper selection of electronic components, stabilized power supply and proper design of float and float guide tube, the long term stability may be increased. Moreover this cylindrical float and cylindrical guide tube may be so selected that their surfaces are highly polished and there is negligible gap between them. Under this condition the space above the float surface may be assumed to be an enclosed chamber and diffused IR wave will behave like radio wave [16] and will be unaffected by liquid vapour and other similar obstructions.

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