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DISTRIBUTED OPTICAL FIBER SENSORS FOR CONTINUOUS LIQUID LEVEL TANK GAUGING

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1.0 PROGRAM OVERVIEW

This report presents the results of a three and a half-year project sponsored by the Department of Energy (DOE) Invention and Innovation Program. The improvement of tank gauging technologies would save unnecessary fuel consumption and unnecessary inventory usage. The Noverflo Multipoint Tank Gauging (NMTG) is a family of fiber optic sensor arrays designed for the oil and gas industry, the transportation industry and the food/beverage processing industries. The NMTG introduces completely a new concept to tank gauging.

The NMTG technology is covered by four U.S. Patents, (5,828,798, 5,982,959, two pending).

The NMTG is distinguished from similar products by the unprecedented simplicity that enables it to perform both low and high accuracy measurements at a very low cost. This simplicity results from the loop geometry of the sensors. The sensors are easily fabricated and installed and are adaptable for field modifications. Since only light passes through the sensor the NMTG sensors are intrinsically safe. Because of their very low cost the sensors are ideally suited for use in arrays or suites. For tank gauging, the NMTG sensors are arranged in vertical arrays; the wet or dry state of each sensor is displayed by an entirely new versatile and user-friendly data acquisition system. This system is capable of monitoring, locally or on the Internet, hundreds sensors and numerous external devices without upgrades to existing systems.

The NMTG is among very few technologies that measure the location of a liquid surface directly. The NMTG senses the presence of the liquid, identifies its chemistry and sends a direct binary message to a simple data acquisition unit. Independent inputs on other parameters are not required. Other technologies measure level indirectly and rely on various inferential techniques, requiring knowledge of the properties of the liquid and the media above it. Indirect methods contain inherent errors. Radar, for example, relies on signals that are reflected from the surface of the liquid. A conversion of the transient time of the signal to fuel level requires accurate information about temperature, surface absorption, the tank's reference height and the water level at the bottom of the tank. Indirect measurements of liquid level are inherently unreliable for high accuracy measurements and are more expensive than direct measurements.

In addition to tank gauging, the NMTG can be used to detect tank leakage, bacterial corrosion potential and the presence of water and sludge. The NMTG can measure levels in liquids of nonuniform densities in a practical and cost effective manner. It is the world's only technology that can perform continuous remote measurements of the liquid density at any tank level.

The U.S. process level gauging market reached $383M in 1998 (U.S. Inventory Tank Gauging Industry, 6th Ed.). More than 20 different technologies are being offered on the market for many different applications. Unlike other technologies, a single NMTG unit can simultaneously perform several functions and operate in varying environments. For example, radar gauges, costing $5000 are used for custody transfer where an accuracy of better than 1/8" is required. This does not include the cost of additional sensors to identify the water/product interface. In contrast, the cost of the NMTG with the capability of identifying water/product interfaces is under $1500.

Prototype NMTG tank gauges were tested on a locomotive and on tanks at an industrial site. The test results have clearly demonstrated that the NMTG was easy to install, operated reliably in harsh environments, and required no maintenance.

The major features of the NMTG are listed below in Table 1. Table 2 identifies the advantages that the NMTG technology offers over several traditional technologies.

Table 1 - Major Features of the NMTG Technology

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Features	NMTG	Ideal Tank Gauge (Oil&Gas Journal, March 3, 1997)
High reliability, maintenance free	√	√
Repeatability 1/16”	√	
Measures levels to 1/8”	√	√
Measures Innage	√	√
Low initial and maintenance costs	√	√
Measures product densities continuously to 0.001gr/cc.	√	√
No moving parts	√	√
Connected to a PC or a bar graph at tank side	√	
Identifies water/product interface	√	
Intrinsically safe	√	
Adaptable to different tank access ports	√	

Table 2 – Comparison of Selected Continuous Liquid Level Gauging Technologies

Technology	No Moving Parts	High Accuracy	Measures Densities Continuously.	Operates In Shifting Densities	Operates in stratified fluids	Identifies Water/prod Interface	Measures Corrosion Potential	Low Cost
NMTG-X	√	√	√	√	√	√	√	√
NMT G-Z	X	√	√	√	√	√	X	√
NMTG-L8	√	X	X	√	√	√	√	√
Radar	√	√	√	√	√	X	X	X
Hydrostatic	√	X	√	√	X	X	X	√
Magnetostrictive	X	√	X	X	X	√	X	X

Technology	Measures Innage	Calibration Not Required	No Moving Parts	Web enabled Without upgrades	Tank Height >50	Remote Monitoring $100/tank < ($20 for each additional tank,)
NMTG-X	√	√	√	√	√	**X**
NMT G-Z	√	√	**X**	√	**X**	**X**
NMTG-L8	√	√	√	√	√	√
Radar	√	**X**	√	**X**	√	**X**
Hydrostatic	**X**	**X**	√	**X**	√	**X**
Magnetostrictive	√	**X**	**X**	**X**	**X**	**X**

2.0 OPERATING PRINCIPLE

The NMTG consists of a vertical array of fiber optic sensors mounted on a support, which can be a solid rod or a flexible wire. For high accuracy measurements, the sensor support incorporates one or more pressure sensors depending on whether the vapor space is vented and whether the height of the tank exceeds 50 feet. The rod or wire is housed inside a pipe, of which one end is projected into the tank and the other end terminates in a signal conditioning enclosure at the top or the side of the tank. The data from the electrical enclosure can be transmitted to a bar graph or to a PC through a USB connector or RS-232. Alternatively, the customer may use a 0-5 VDC or 4-20ma display meter.

2.1 Low Accuracy Level Measurements, NMTG-L

In many industrial applications, low accuracy of liquid levels' measurements is sufficient to meet customer requirements. In such cases, the high and low levels and several points in between are sufficient. The high and low signals activate an alarm or a pump as the case maybe.. The NMTG high-level signal meets the Association of American Railroads Locomotive Fueling Interface Standard (LFIS). Figure 1 shows a typical tank mounting of the NMTG for 10 % -15% measurement accuracy.

2.2 High Accuracy Level Measurements, NMTG-X

Moderate and high accuracy level measurements are required for inventory control and custody transfer respectively. Figure 2 is a schematic of the NMTG for such applications. The main difference between NMTG-L and this design is the pressure sensor at the bottom of the tank.

In many instances, the density of the liquid in the tank is not uniform; it may vary due temperature gradients or due to stratification when the tank is used interchangeably for fluids of different densities. The NMTG technology offers several options for measuring liquid levels in tanks with varying liquid density.

2.3 Moderate density changes - NMTG-X

The NMTG-X was designed for use where density gradients, arising from temperature gradients are relatively small. Referring to Figure 2, the level in the tank is given by

1. $H = H_n + h$

2. $(P- P_n) = (\rho_n)h$

3. $(P_n-P_{n-1} = (\rho_{n-1})S$

Equation 1 simply states that the level is equal to the liquid level, H_n at the location of the Nth sensor plus the level h of the liquid residing above it. Equation 2 expresses the hydrostatic pressure of the top layer and Equation 3 expresses the pressure of the liquid which is confined between. H_n and $H_{n-1.}$ P_n and P_{n-1} may be obtained from a look-up table of P_n vs. H_n or when the liquid is removed from the tank.

When the density in the tank is uniform, $\rho_{n-1} = \rho_n$, and H can be calculated from equations 1 through 3. However, unmixed liquids in large tanks, maybe temperature stratified, and therefore ρ_n of the top layer may not be the same as the density of the layers below it. However, since liquids are good thermal conductors the assumption that $\rho_n = \rho_{n-1}$ will introduce a very small error in level measurements when the spacing between the sensors, S is small compared to the dimensions of the tank D.

4 $\rho_n \cong \rho_{n-1}$ for $S << D$

A combination of equations 1 – 4 results in an expression for the liquid level in terms of known quantities.

5. $H= H_n + (P-P_n)S / (P_n-P_{n-1})$

2.4 Large Density Gradients and Dissimilar liquids - NMTG-Z

An entirely different approach is required when very large density gradients are present. Storage of products with different densities in the same tank ultimately would result in some degree of density stratification. Light oil will float on top of denser liquids. The use of a hydrometer together with a pressure sensor allows the determination of densities and levels in such circumstances.

Figure 3 shows the design of the NMTG for density measurements where there are large density differences between the top layer and the liquid below. This design consists of three components: A float, a pressure sensor and one or two fixed NMTG sensors. The purpose of the float is to measure the density of the top layer; in essence it is a hydrometer that reads the specific gravity electronically instead visually. An array of sensors mounted vertically detects the liquid/air interface with respect to the submerged volume of the float. As depicted in Figure 4, the known location of the sensors and the different signals generated by the wetted and the dry sensors identifies the location of the interface in accordance to Archimedes law.

6. $\rho_u = W/ AF$

W is the weight of the float, A is it's cross sectional area and F is its submerged length. For a fixed weight and a cylindrical float, the density or the specific gravity, s.g. is directly proportional to the number of wetted sensors.

Referring to Figure 5, the level H and the corresponding pressure P at any location are given by

7. $H = F + X$

8. $P= \rho_u F + \rho_b X$

Rearranging gives an expression for H in terms of the known values of F, P, and ρ_u and the unknown bulk density ρ_b.

9. $H = (P/\rho_b) - F(1- \rho_u/\rho_b)$

When the level coincides with a fixed NMTG sensor at H_n, ρ_b can be readily calculated from

10. $\rho_b = (P_n - \rho_u g F)/(H_n-F)$

.

The number of sensors, n that are mounted on the float determines the measured density range that can be attained with a given float.

11 $$n = (\Delta \rho/\rho)\, F/\Delta x$$

For example, when F =42.4cm and Δx= 1.0 mm, 9 sensors will be required to measure a 2% variation in density, which is equivalent to 100ºF swings in water temperature. Therefore, the use of 9 sensors will be more than adequate for most practical applications.

2.5 Interface Detection (liquid/liquid)

For relatively shallow layers of water and emulsions at the bottom of the tank, NMTG-X incorporates several sensors near the bottom that will generate a signal when they become wetted by water. When a tank contains different liquids with relatively large volumes, the density of each liquid can be determined by using an NMTG-Z at each interface as shown in Figure 6. If it is also required to determine the location of the interface, it is necessary to measure pressures, Pn and P_{n-1} at two successive fixed sensor locations,

12. $$Pn/g = X\rho_u + Y\rho_b$$

13. $$P_{n-1}/g = X\rho_u + (Y-S)\,\rho_b$$

Since the densities and the spacing S between the sensors are known, the height of each liquid, X and Y, can be determined from equations 12 and 13 when the liquid is removed from the tank. Equation 13 implies that the liquid is withdrawn from the bottom of the tank.
If the liquid is withdrawn from the top, the equation can be modified accordingly.

2.6 Error Discussion

a. NMTG-X . The accuracy of the level measurements is governed primarily by the accuracy of the pressure sensor. Since the pressure accuracy decreases with the increase in the pressure range of the sensor, the accuracy will diminish as the height of the tank increases. For a 10 ft tank, a sensor with a repeatability of 0.02% FS and a range of 0-5 psi, the error in level will be 0.024". For a 50' tank and a sensor with a range of 0-25psi, the error will increase to 0.120". A 100' tank therefore will require two pressure gauges.

The error associated with the assumption that the density of the top layer is the same as the density of the liquid between the two sensors below. Equation 4 depends only on the spacing S between the sensors and the local temperature gradients. When the sensors are one foot apart and the temperature gradient between H_n and H_{n-1} is 70º F, the measurement error in H is on the order of 3 mm. Such steep local temperature gradients in fuel or oil tanks normally do not exist.

The location of each sensor with respect to the pressure transducer can be determined by lowering the NMTG into a liquid of known density and calculating S from equation 3 as successive sensors contact the liquid. The measured repeatability of a sensor contacting the liquid is better than 0.010".

The above considerations indicate that the measurement error in H is considerably lower than 3 mm when the spacing between the sensors is one foot. With 33 sensors and two pressure sensors in a 100' tank, the measurement error in liquid level is expected to be less than 1/8".

b. NMTG-Z. The accuracy of density measurements depends on the spacing between the sensors. The relation between the change in density $\Delta \rho$ and the spacing Δx is given by,

9. $$\Delta \rho = (W/A F^2) \Delta x$$

When $W/A = 42.4$ gr/sq.cm, $F = 42.4$cm, $\Delta x = 1.0$mm, s.g. accuracy is 0.002 gr/cc.

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3.0 SENSOR DESIGN

Light propagation in an optical fiber can be characterized in terms of a bound mode and a radiation mode. According to the ray theory, light modes that strike the core/clad interface at angles larger than the critical angle confine the energy to the core region. Only a small amount of energy travels in the clad region parallel to the core/clad interface in a zone commonly called the evanescent zone. In the radiation mode, the light at the core/clad interface is refracted into the cladding in accordance with Snells' law, and is lost to the environment. As a consequence of Snells' law, the radiation mode occurs when the incident angle is smaller than the critical angle or when the index of refraction of the core is smaller than the index of refraction of the medium, n, which it is in contact. Many biosensors utilize the evanescent zone to generate a recognition signal; the NMTG sensors utilize Snells' principle to generate the recognition signal. Since the magnitude of the radiation signal is by orders of magnitude large than the evanescent signal, simple low cost instruments can be used to detect the radiation signals.

As shown in Figure 7 and Patent No 5,828,798, the innovative feature of the Noverflo sensor is its unique loop configuration and the tapered apex cross section. These factors minimize the radiation loss when the sensor is exposed to air and maximize the radiation loss when the sensor is exposed to the target liquid. The difference between the light loss to the air and the light loss to the liquid is used as the recognition signal. The loop of the NMTG sensors can be configured to provide maximum sensitivity and discrimination between different liquids. Figure 7A shows the sensitivity of the sensor to variation in the index of refraction, n . The sensor can distinguish between water and ice, clearly indicating that it can detect changes in n., Δ n, less than 0.02. When the layer of ice is thin, fraction of a millimeter, the sensor "sees" both ice and air and therefore the signal output falls somewhere between air and ice.

4.0 DATA ACQUSITION AND DISPLAY

As can be seen in Figure 7, two different methods are available for converting the wet/dry signal to liquid level and to specific gravity measurements. The first method is based on using discrete phototransistors while the second method is based on using a PC camera.

4.1 Phototransistor Based Design.

In this method one end of each sensor is connected to a separate phototransistor while the other end is connected to a single LED common to all sensors. The analog signal from each transistor is converted to a digital signal by an OP-Amp, which is used as a comparator. The digital output from the comparator is governed by a threshold, which is set by a voltage divider, as shown in Figure 8. Each sensor generates either 1.0V or 5VDC depending on whether the sensor is dry or wet. When these signals are summed up by a second OP-Amp, the corresponding output is directly proportional to the number of wet sensors.

The above design consumes about 25ma at 5VDC for 8 sensors. To lower the power consumption, to 2.5 ma, a microprocessor-based design is used. Each sensor is connected to a separate LED, which is pulsed sequentially, as shown in Figure 9. The operation of a single sensor proceeds in five steps:

1. With the LED off, the sensor output is measured
2. The LED is turned on
3. After a pre-selected interval of time, about 100 {u}µsec, the output of the sensor is measured again.
4. If the output exceeds a threshold value (as determined by a previous calibration), the sensor is considered to be dry. If the output is less than the threshold, then the sensor is considered to be wet.
5. After the output has been recorded, the LED is turned off and after a pre-selected time, about one second, the next LED is turned on. When a sensor is wet, the corresponding LED will be turned on for 1 second.

The phototransistor based design is identified by the letter P**,** for example a high accuracy NMTG with 8 sensors will be identified as NMTG XP8

4.2 Camera Based Design.

In this design, the light from one end of the sensor, Figure 10, is projected on a low cost webcam camera. A wet sensor projects a very low intensity light images while a dry sensor projects a high intensity image. The fibers are spaced at about 0.1" apart at the camera/fiber connector. The number of sensors that is wetted at any given time is simply obtained by counting the number of fibers that are lit at that time.
A software package that performs this simple counting task, NMTG- C-1.0, requires (1) Windows 95,98 or ME based computer, and (2) a Camera that supports VFW driver and Visual Basic 6.0 SP5 runtime files. The software saves a snapshot from the camera into an

uncompressed Windows bitmap file and counts the number of active lights that are displayed in the image file. Figure 10A is an example of how this software is used to display continuously the amount of liquid in a tank.

The camera based design is identified by the letter C**,** for example, a high accuracy NMTG with 32 sensors will be identified as NMTG XC32 .

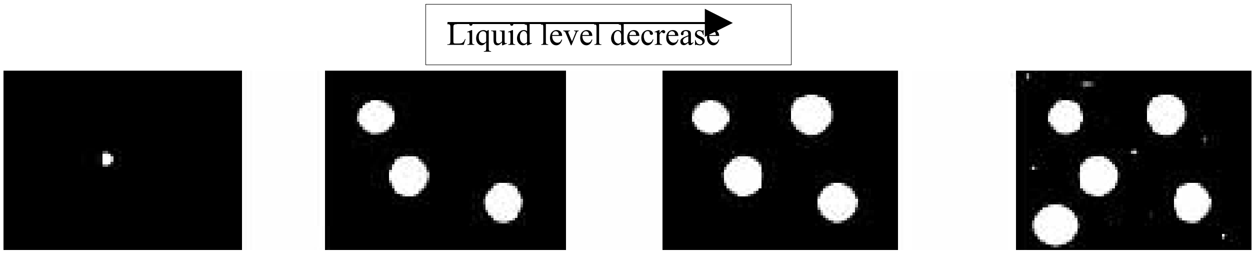

Figure 10 –Images of sensors' ends captured with a low cost PC camera. The number of lights in an image corresponds to the number of dry sensors in the tank at any given time.

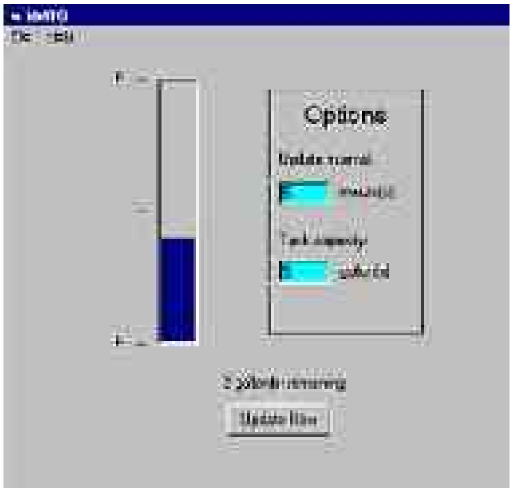

Figure10A– PC display of the number of wet sensors, which also represents liquid inventory in a given tank.

4.3 Design Selection.

When the number of sensors is relatively small, less than 16, and it is sufficient to display the level on the tank or in its vicinity, it is more economical to use the phototransistor-based design. On the other hand, if the number of sensors exceeds 16, it is more economical to use the PC-camera based design. In multi-tank applications, where each tank is equipped with an NMTG, it would be more cost effective to use a hybrid design as shown Figure 11. In this design, each sensor activates a corresponding LED, which in turn is projected on the camera with short optical fibers. The connector can accommodate more than 700 fibers; therefore, there is practically no limit to the number of tanks that can be monitored simultaneously. Minor modifications of the present software would be required for multi-tank operations.

5.0 COST CONSIDERATION

The NMTG is fabricated mostly from off-the-shelf components. Other components are simple and are easy to fabricate. The assembly of the final product is also simple and does not require highly skilled labor. The follow cost estimate is provided as an illustration. This estimate is based on the fabrication of a minimum of 50 NMTG-X units, each incorporating eight sensors and a single pressure sensor for installation in a 10' tank.

a. Off –the- shelf components

1.	WebCam	$20.00
2.	Camera Enclosure (NEMA 4X)	15.00
3.	100' plastic fiber @$.02/ft	2.00
4.	LED & Connectors	3.00
5.	Pressure sensor Rep 0.02%FS, + 10' cable	400.00
6.	Mounting hardware	10.00
	Total	**450.00**

a. Fabricated parts (Labor @ 15/hr

1.	Sensor Supports (attached tp pressure cable)	4.00
2.	Sensors (8),	5.00
3	Fiber/Camera Interface connector (1)	10.00
3.	Sensor Supports (attached to pressure cable)	4.00
4.	wires, brackets	15.00
5.	Assembling, Testing & Shipping	30.00

Total	**68.00**

Fabrication Cost of NMTG-XC 8 (Camera Based Design) ----- $518

The above estimate clearly indicates that the main cost of the NMTG-X is the cost of the pressure sensor. For tanks larger than 10 feet, the labor cost will be higher for handling longer cables. In contrast, NMTG-L would cost about $150.

The cost of NMTG with phototransistors is slightly higher than the cost of NMTG which uses a camera, as long as the number of sensors does not exceed 16. The cost differential between these two designs becomes more significant when the number of sensors exceeds this number.
It is easy to appreciate the cost advantage of the NMTG over other technologies. To increase the accuracy of tank gauging with a single hydrostatic sensor, some manufacturers are adding systems with pressure sensors at different tank levels. The NMTG, in essence, substitutes these additional pressure sensors with the much less expensive NMTG sensors. While the cost of a high accuracy pressure sensor is at least $400, the cost of the equivalent NMTG sensor is under $6. Therefore, the accuracy of measuring levels and densities by the hydrostatic method is ultimately limited by the cost of the pressure sensors. In contrast, the cost of the NMTG is not very sensitive to the number of sensors.

6.0 TECHNOLOGY STATUS

6.1 Sensor developments and testing. Sensor development has proceeded from laboratory tests to long term field-testing and limited commercial use. . Laboratory tests that extended over a period of eight years included studies of: (i) compatibility of coated and non-coated sensors in various liquids, (ii) temperature effects, (iii) aging, (iv) stress effects, and methods of sensor support. Table 3 provides a summary of the tests, which have been conducted more recently.

TABLE 3 – Summary of NMTG Sensors Performance in Various Liquids
(0.5mm &1.0 mm plastic fiber – Distributed by MORITEX Inc)

Chemical	**Strength %**	**Coating/Heat treated**	**Date exposed**	**Exposure time (Hrs)**	**Date or hrs**	**Date or hrs**	**Date or hrs**	**Date or hrs**
HCL	100		1/17/02	24 OK	150			11/13 02 OK
NaOH	100			24 OK	150			OK
H2SO4	50			Failed				
H2SO4	30			24 OK				
Phos. Acid	85			Failed				

Methanol	100	Epon160/3218 (4:1)	1/18/02					
H2SO4	50	Epon160/3218 (3:1)	1/24/02		170			OK
Phos. Acid	85	Epon828/3218	1/31/02			840		Fail
Diesel	8 Sen Prototype	As Received	02/21/02	07/11/02 OK				
Diesel	8 Sen Prototype	As Received	04/10/03	09/04/03 OK				
Phos. Acid	85	Not Coated, low stress	03/06/02			840	1010	Fail
H2SO4	100	Epon 828/3218	04/04/02	3 hrs OK				
Gasoline		828/3770 (3:1)	04/19/02	Failed 06/04/02				
Gasoline		EverFix	07/16/02	40hrs Fail				
Gasoline& Alcohol		Heat Annealed	09/04/02 5sensors	5min OK				
Gasoline		HA	09/05/02 10sensors	40hrs OK	170			
Gasoline		HA	09/12/02 8 sensors	264 OK	10/14 OK			
Gasoline	8 sen Prototype .	HA	09/20/02	04/10/03 OK				
Phos Acid	42	HA	11/13/02	24hrs OK	140	03/17/03ok	04/25 03	
Phos. Acid	85	HA		24hrs OK	140	OK	OK	
H2SO4	50	HA		24hrsOK	140	OK	OK	
H2SO4	100	HA		24hrsOK	140	OK	OK	
NaOH	50	HA		24hrsOK	140	OK	OK	
Acetone			03/17/03				Fail	

Third party field-testing of point level sensors has been conducted at the Rocky Mountain Oilfield Testing Center in Wyoming and at the AAR Transportation Technology Center in Colorado. Float mounted sensors for the detection of thin oil layers in sumps were sold to several power plants in the nineties by Action Sensors, Inc. Wendel Carolina.

In September 2000, the U.S Department of Energy (DOE) approved a budget of $279,284 for the joint development of a “DISTRIBUTED OPTICAL FIBER SENSORS FOR CONTINUOUS LIQUID LEVEL TANK GAUGING,” Grant N0. DE-FG36-00GO10613. This work was completed on March 31, 2004. Task by task description of this program is provided at the end of this technology overview.

The program was focused on the development of six NMTG-L prototypes for land and railroad applications. Three prototypes, incorporating 8 sensors each, were tested in a fuel tank at an industrial site in Pennsylvania. Each unit operated for approximately five months. The first two units operated in diesel and the third unit in gasoline. Each prototype was examined for any signs of aging, and no such signs were found. All units used the phototransistor-based design; the camera-based design was not tested because a PC was not readily available. Figure 12 is a photograph of one of the units after end of the testing period (five months).

Because of extremely high vibrations, large temperature swings, and dusty environments, locomotives present a very demanding test bed. The three prototypes that were fabricated for the locomotive tests are shown in Figure 13. The first NMTG -LP16D, a 16-sensor unit, was mounted in October 2002 on Locomotive 8811 owned by Norfolk Southern. NS 8811 is transporting coal, in W. Virginia; it is scheduled for maintenance in June 2004. The unit was inspected in May 2003 and the indicated level agreed with sight glass readings, Figure 14. The First prototype will be replaced by the second prototype in June 2004.

The Camera based NMTG-C has been tested in the laboratory extensively, Figure 15 and 16 show a hardwired and a wireless unit respectively.

6.2. NMTG-Z. Two working models were fabricated to test the basic concept and to identify any potential problems. The first model was a 2” x 7” cylindrical float and the second model was a 0.75” x 4.0 flat float. The models are shown in Figures17, and 18. The detection of the water/air interface was implemented with two 0.5-mm plastic fiber sensors spaced at 1.0 and 0.5 mm. An LED monitored the wet/dry status of each sensor. The addition or subtraction of weights to the float located the interface. Large number of tests established that the interface could be located within 0.5mm.

7.0 CONCLUIONS

All the basic R&D for the commercialization of the NMTG- L has been completed. Four prototypes, totaling 40 sensors, have now operated successfully in harsh environments exceeding 1000 hours of combined operation in diesel and gasoline. Demonstration of the NMTG –X and NMTG –Z in large tanks is the next step in the R&D phase of this program. Because the above designs are very simple and are based on a heavy use of off –the –shelf components, we do not foresee any technical difficulties that would impede the commercialization of these devices within a short period of time.

The NMTG brings to the marketplace capabilities that currently do not exist. It allows the customer to tailor a single technology to his specific requirements. For example, when a customer needs to perform accurate fuel level, bottom water and density measurements in large tanks, the use of a conventional system would require the purchase of a radar, a separate probe for water detection, and at least two pressure sensors to measure densities. The NMTG can measure these three parameters with a single instrument and a single mounting.

In numerous applications, very accurate level measurements are not required. However, in today's market, it is difficult to tailor the required accuracy to available instrumentation. Thus, a customer may have to buy more accuracy than it needs. For example, to measure levels electronically in a 6' tank with 15% accuracy, one may use a pressure sensor (1%FS) costing between $100 and $150 without the display. NMTG-L, on the other hand, can measure levels within 12.5% for less than $50 without the display.

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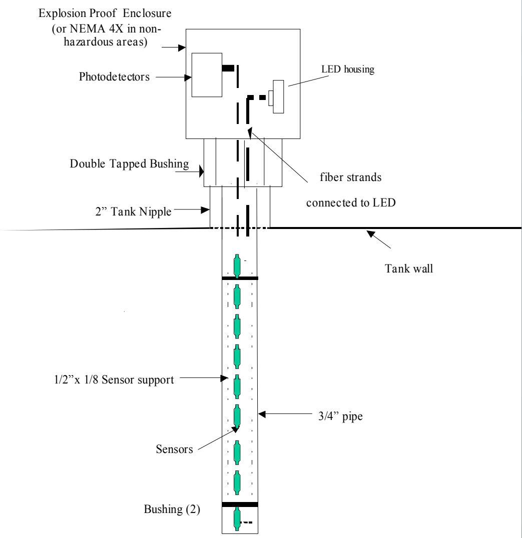
8. FIGURES

Figure 1- Typical NMTG-L Tank Mounting



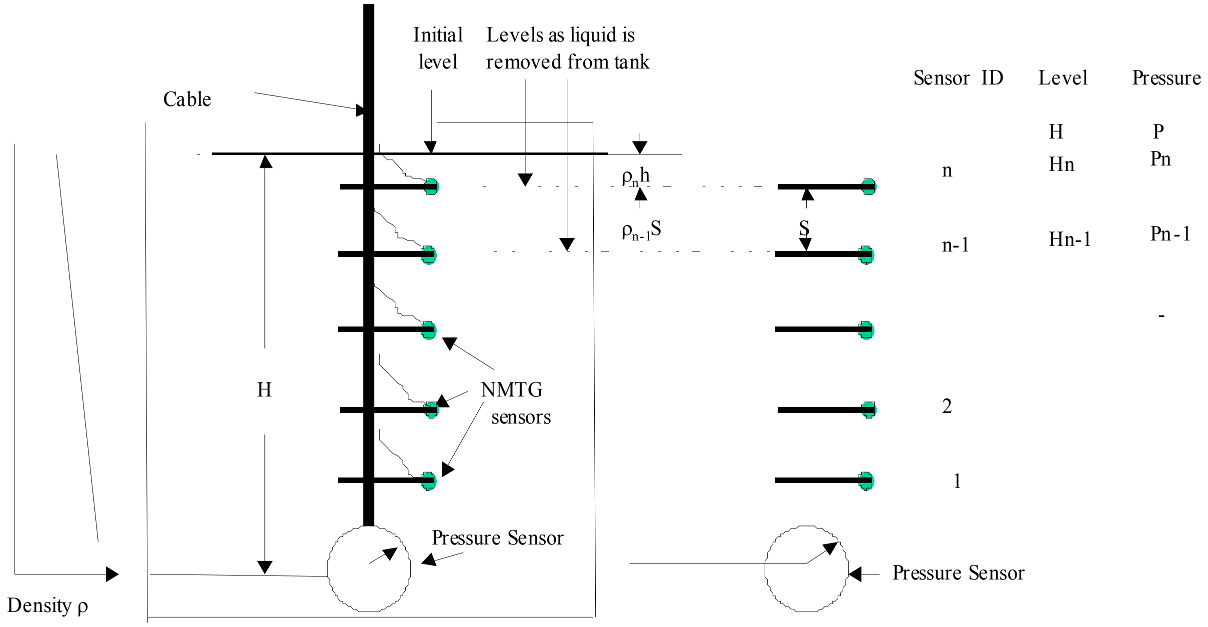
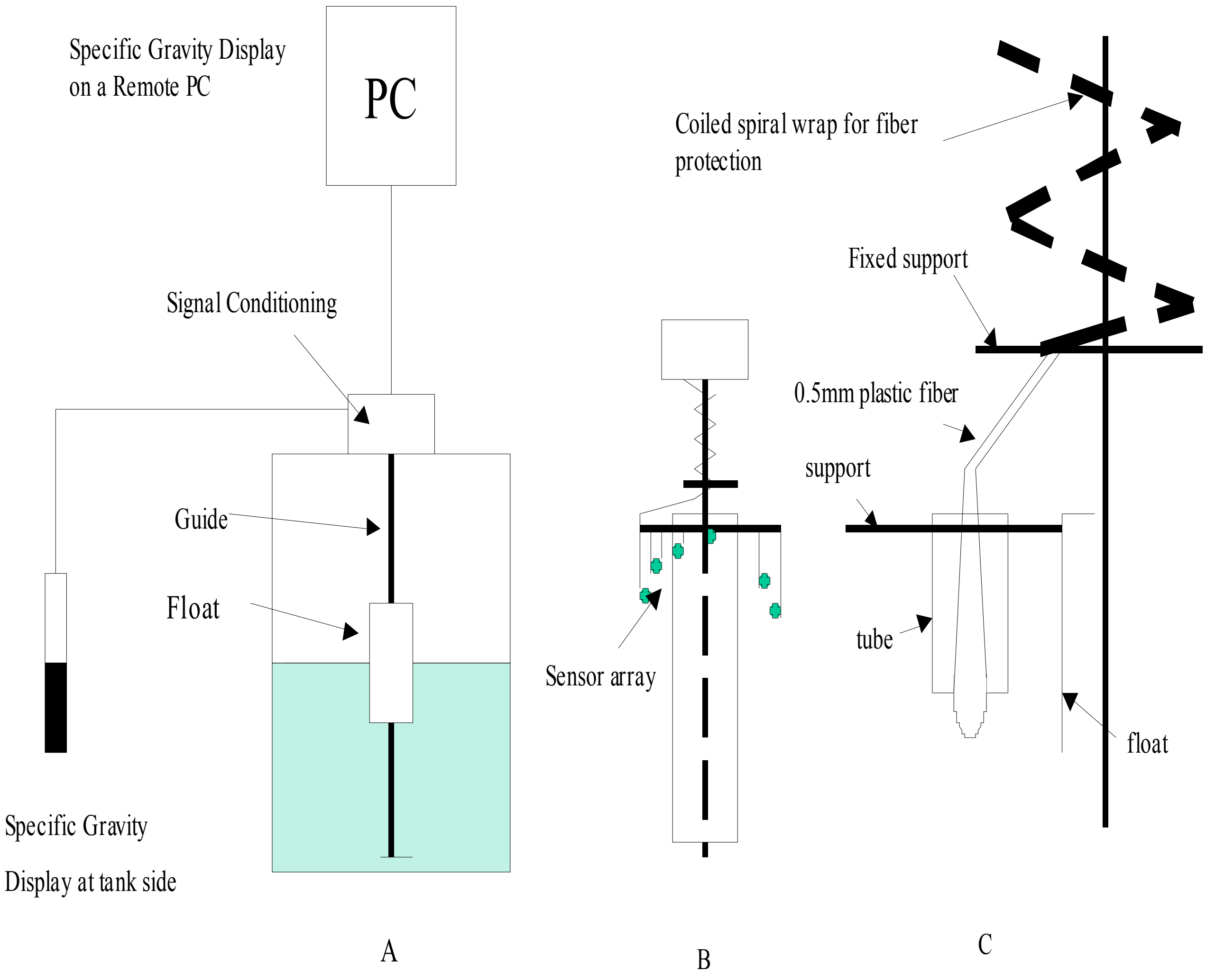
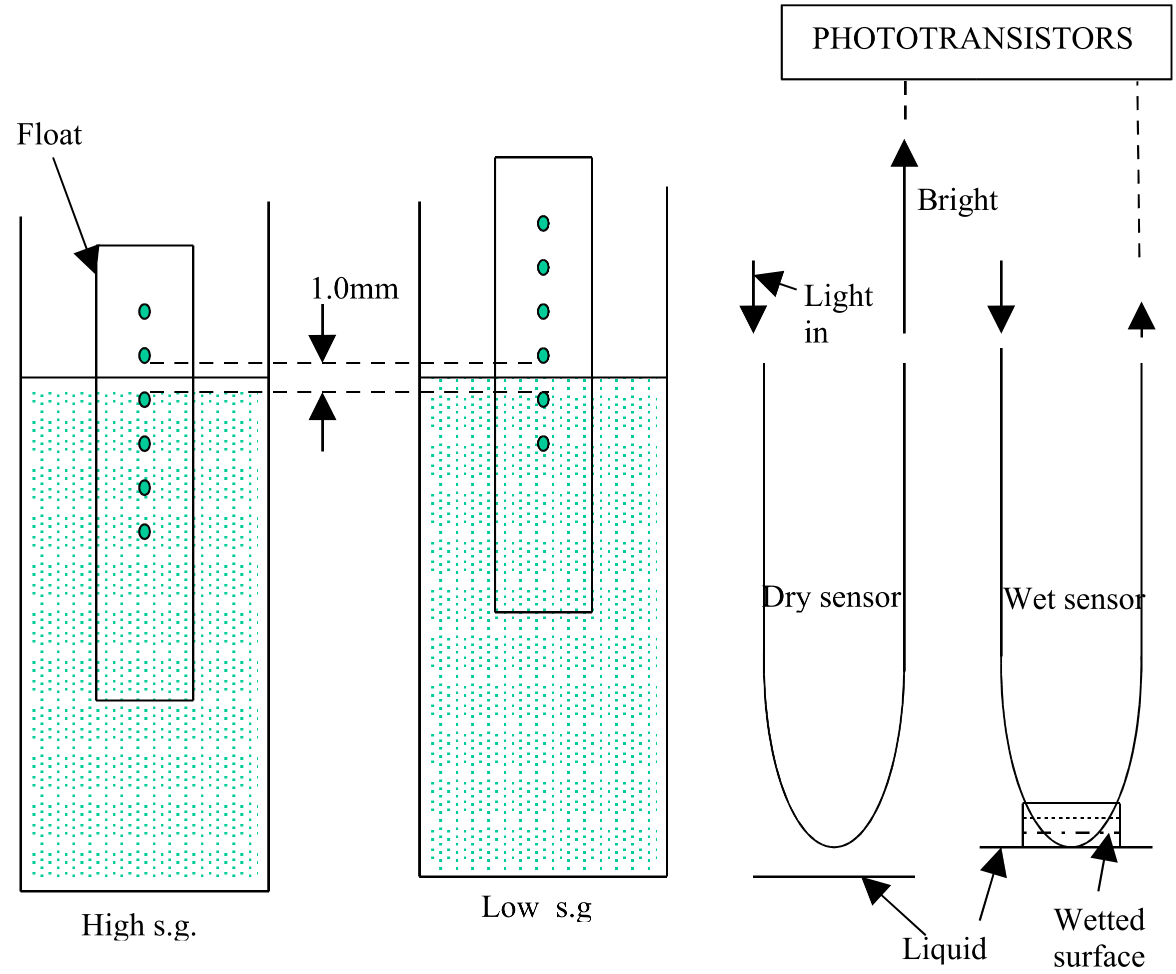


Figure 2- Nomenclature used in the derivation of Equation 5



A - Basic Components of the electronic hydrometer
B - Sensor attachment to the float
C- Sensor leads and connections to signal conditioning unit

Figure 3 - Schematic of NMTG-Z Design



The number of sensors immersed in the liquid is proportional to the specific gravity, s.g.

Figure 4- Principle of specific gravity measurements. The light signal to a photo sensor significantly changes when the apex of the sensor just contacts the liquid. Liquid rise due to surface tension provides ample wetted surface

Figure 5 Nomenclature used in deriving Equation 9

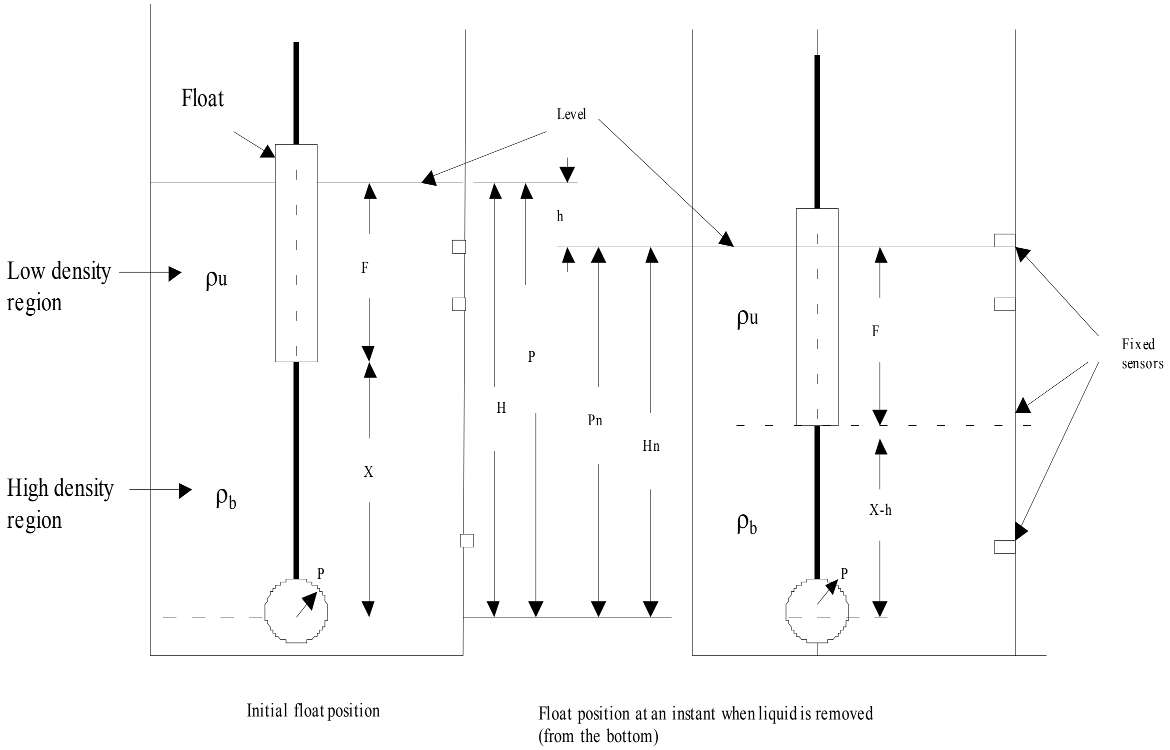
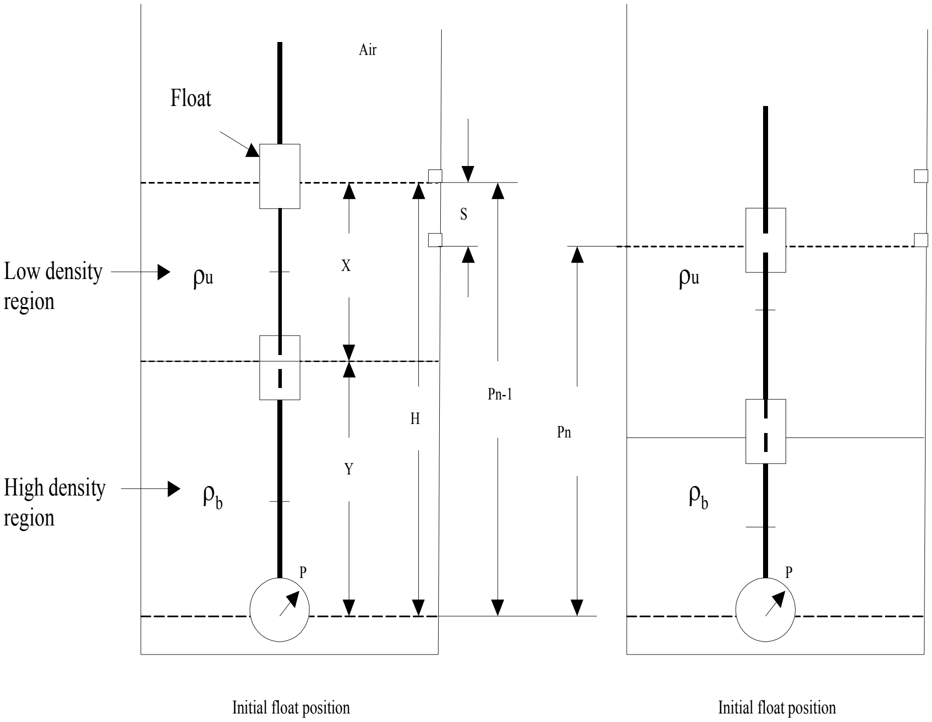


Figure 6 -Nomenclature used in deriving Equation 12 &13



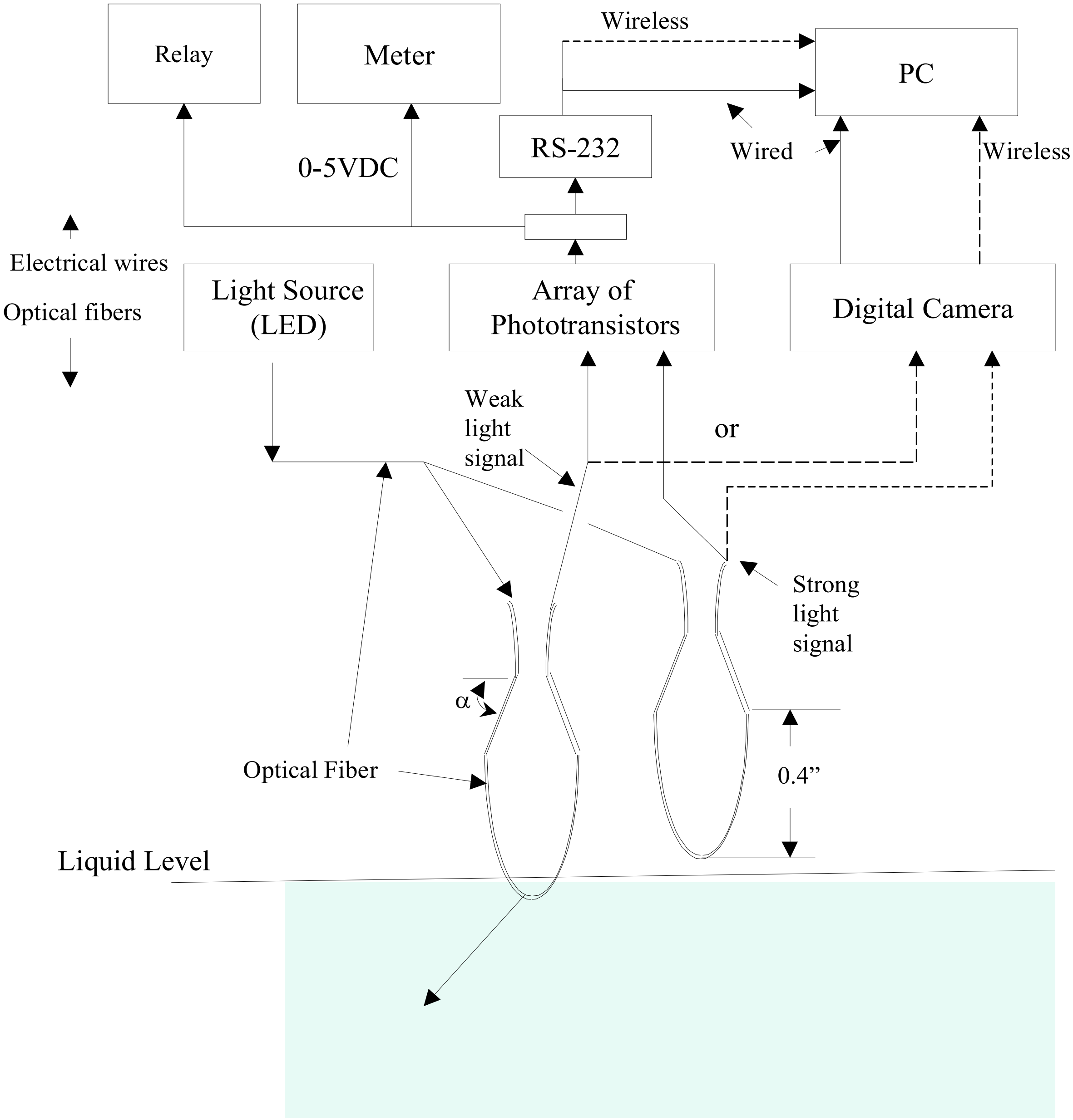
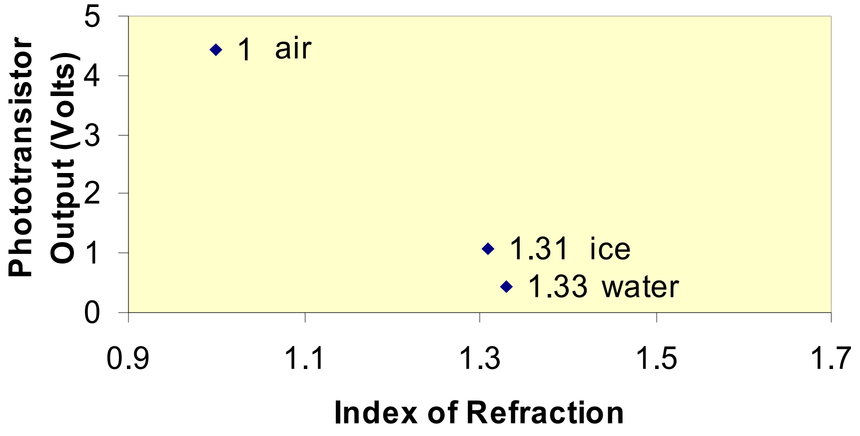


Figure 7 Principle of Operation- sensor’s contact with the Liquid allows the light to escape; wet and dry sensors produce different voltage outputs and different images on the camera.

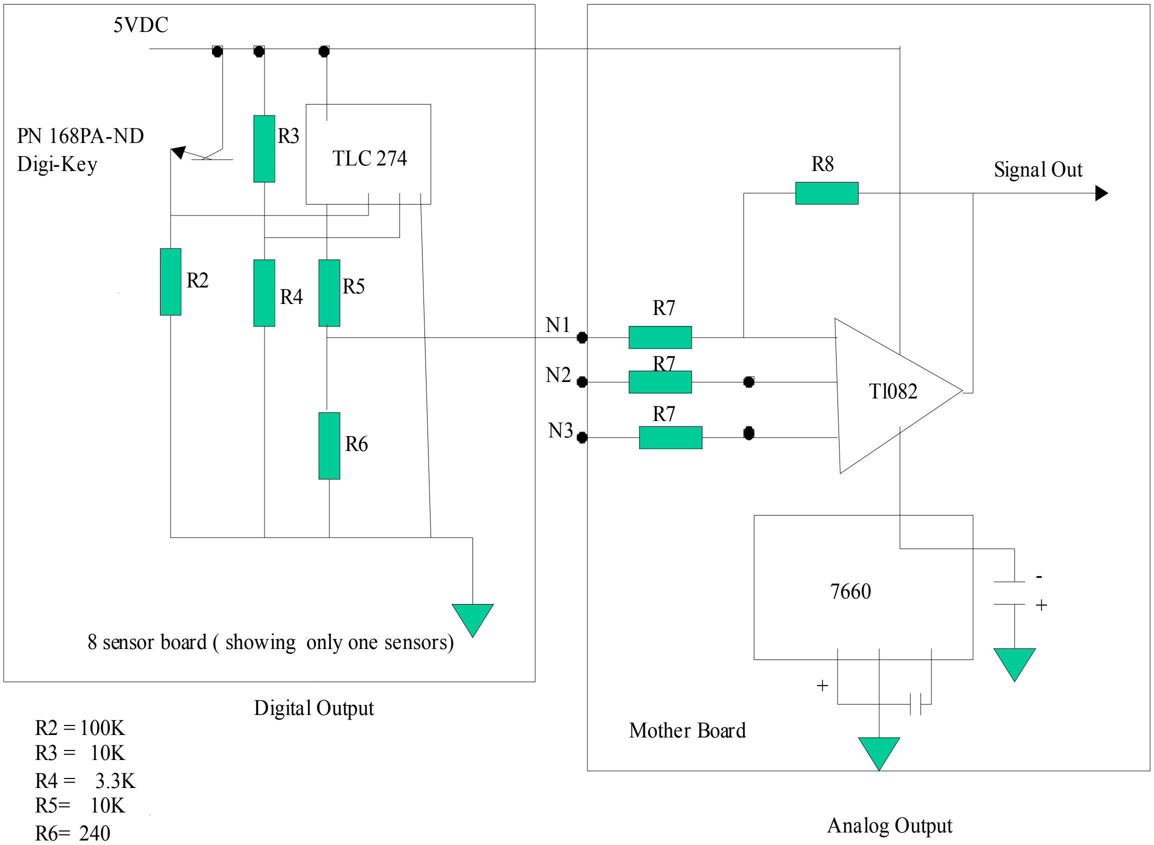
Figure 7A - Sensor Response to Variation in the Index of Refraction



X (0.45)

Water

n=1.33



R2 = 100K
R3 = 10K
R4 = 3.3K
R5= 10K
R6= 240
R7= 100K
R8= 10K

Figure 8-NMTG-P Schematic

Figure 8A – 32 Sensor PCB Stack for the Schematic of Figure 8

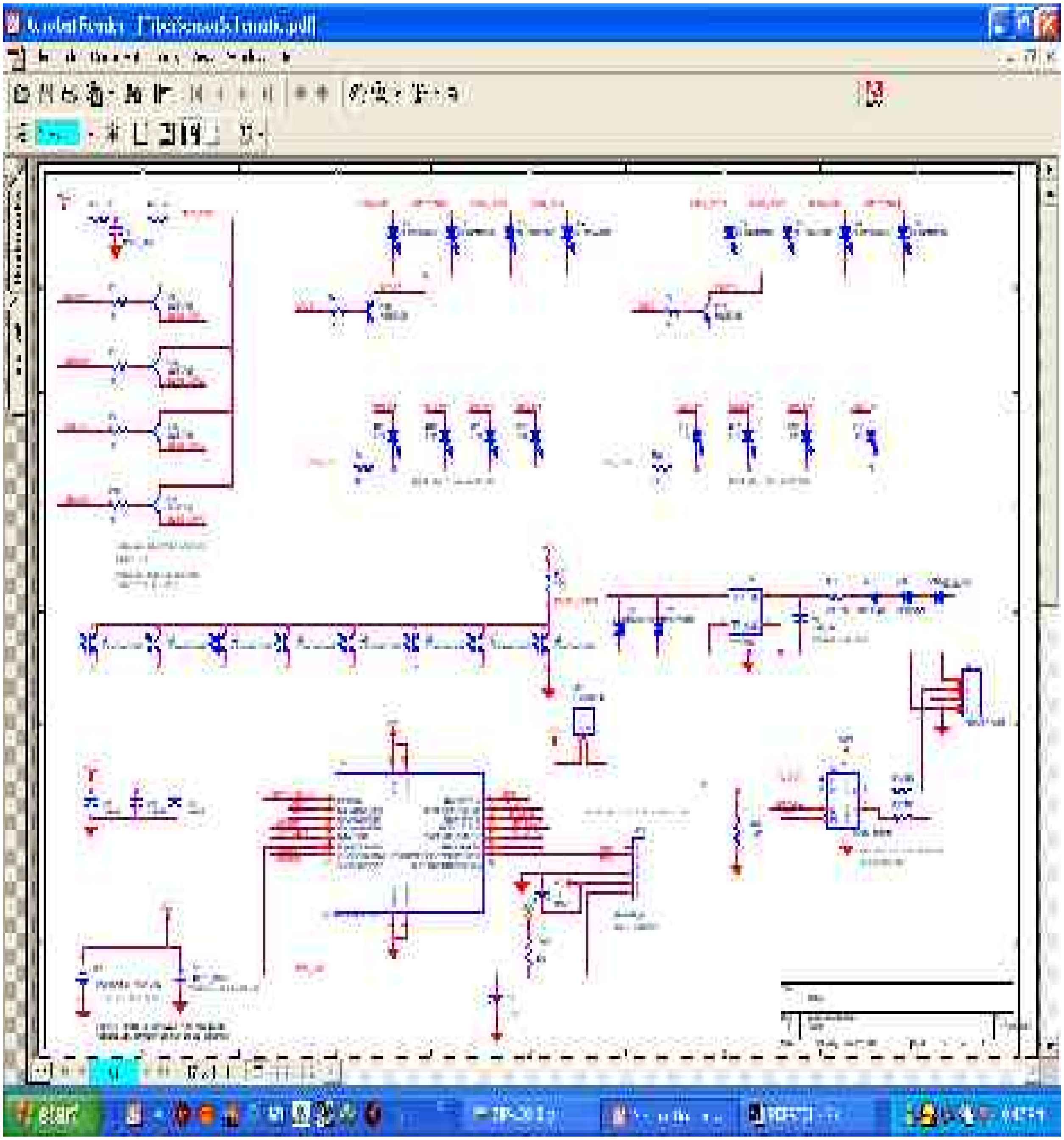


Figure 9 –Pulsed Sensor Design for Wireless Applications

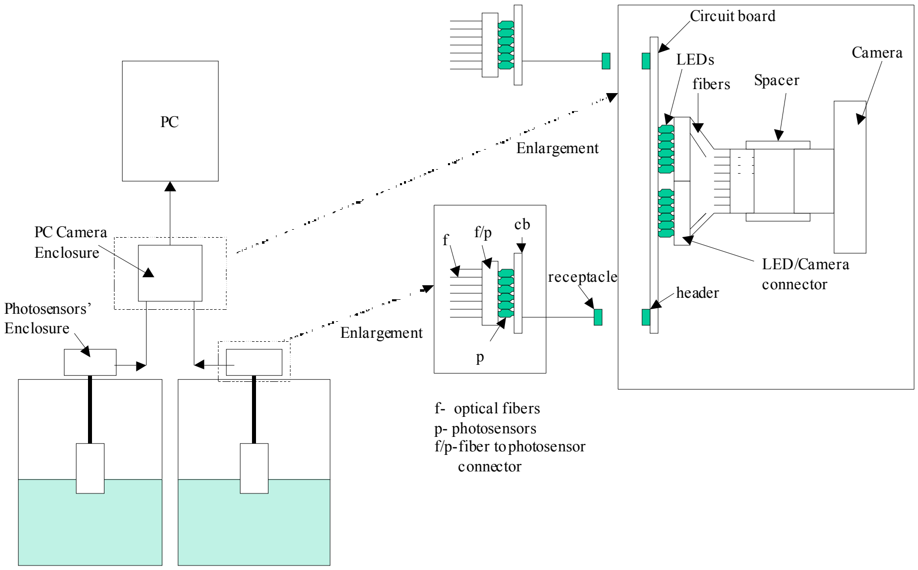


Figure 11- Schematic of multi-tank SG monitoring

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Figure 12- Prototype for stationary tanks

Figure 13 – Prototypes for locomotive applications

Figure 14- Locomotive Prototype (eight months in operation)

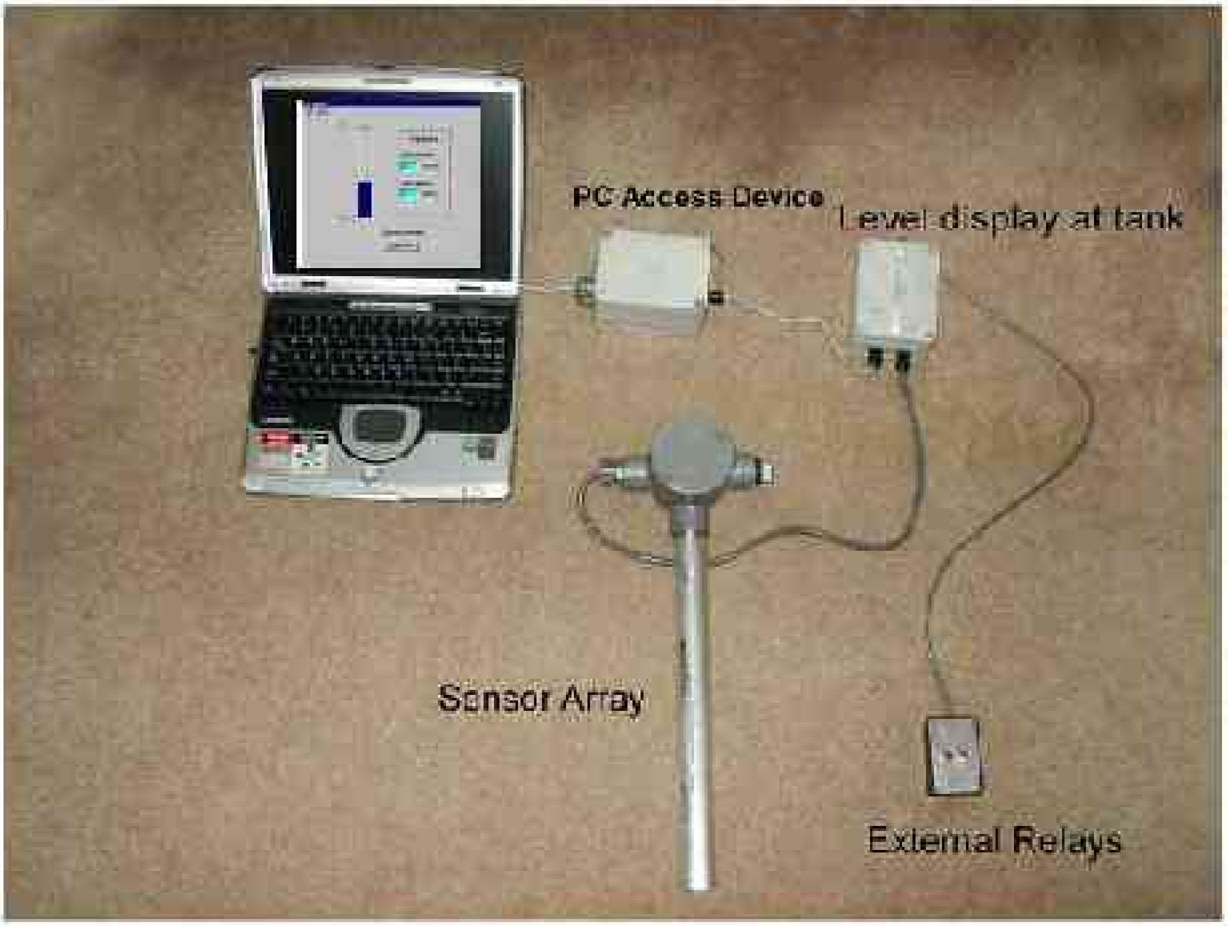

Figure 15- Camera based design for tank gauging and external relay monitoring

Figure 16- A test unit for wireless communication

Figure 17- Working models for s.g measurements

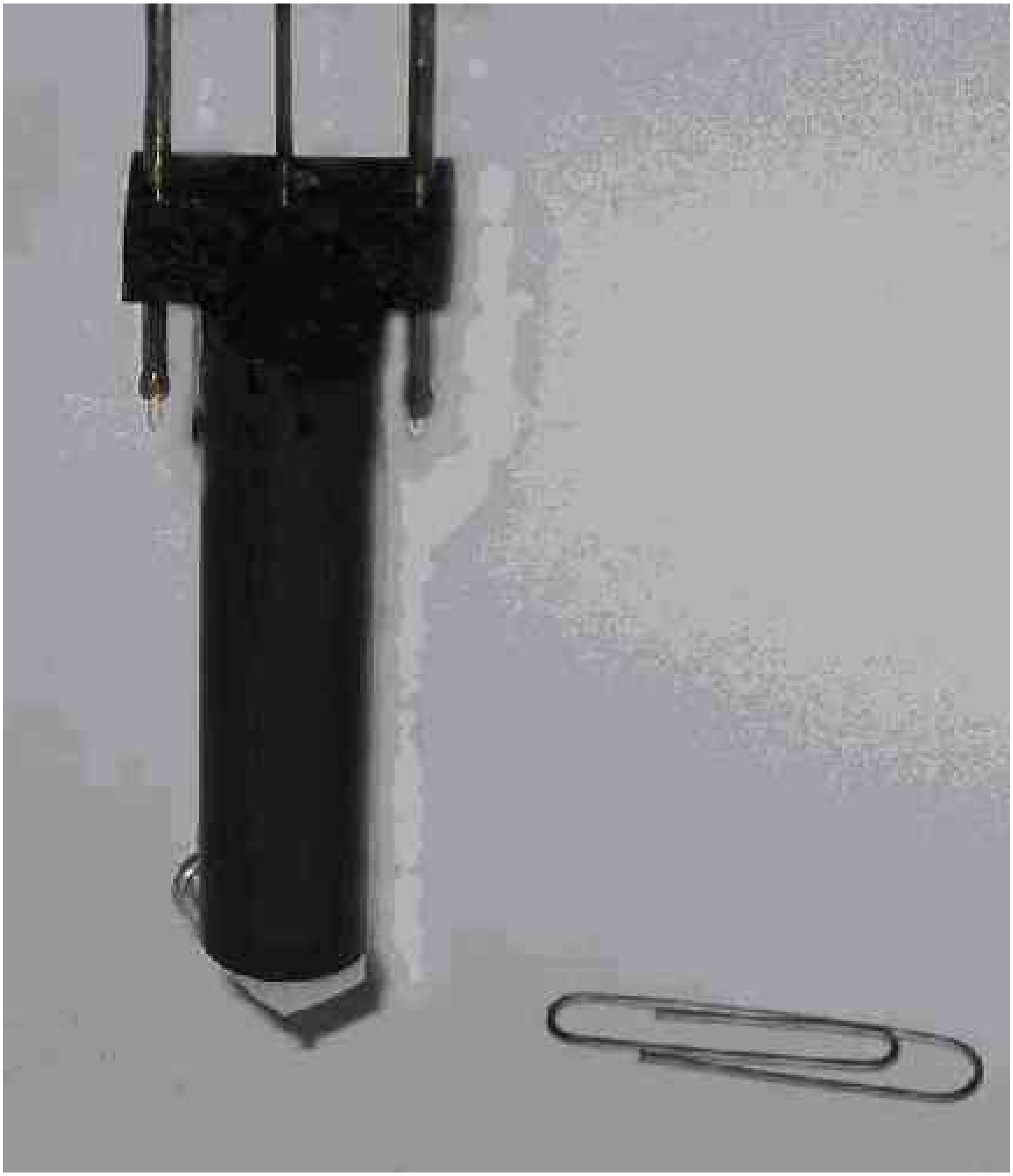

Figure 18- Float Mounted Sensors