Liquid Level Measurement using Laser Beam Modulated by Spread Spectrum Signals

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Abstract - In this work, a novel system for measuring the level of oil at a tanker is presented. This kind of measures is currently carried out by microwave systems but the obtained precision is not completely satisfactory. We have been developed an optical alternative method to measure the distance to crude oil liquid surface with higher precision (±1 mm. in a range of distances from 1 to 30 m). Laser system is also safety-regulations compliant for the crude oil environment. This system is based on the use of a laser beam spread-spectrum MLS-coded modulated signal. The laser bean is pointed to the petrol surface. The receiver evaluates the correlation between the photocurrent received after the scattering of the spread laser bean with delayed replicas of the MLS-coded optical carrier as a way of obtaining an exact estimation of the delay.

1 INTRODUCTION

Nowadays, there are lots of applications in which a precise measure of the distance to an object is required. Most of commercial systems are based on measuring the propagation delay, calculated as the time interval between one signal emission and arrival. Lasers, due to their spatial and spectral coherence, allow very precise determination of the position of the object to be measured. There are several systems of distance measurement using infrared radiation. We can group them in two main categories: interferometers (1) and electro-optical (2). Interferometers measure directly over the optical radiation but need complex sources of radiation and high-cost receivers. Electro-optical measures are accomplished after an optical-electrical conversion and usually are based on using an electrical sub-carrier over the optical signal. Then, variations over one parameter (phase, amplitude, frequency...) of electrical received signal (after reflection or scattering) are calculated. We can summarize the most used methods for this kind of measurements as follows:

- *Time of Flight.* A short light pulse is sent to the liquid, while a fast counter is started. When the pulse echo is received, the counter is stopped (fig 1).

Distance is obtained as the product of the light speed, and the clock period by the counter value. Because the resolution needed, this method is unpractical, as the light moves 2 mm (1 mm forth and back) in 6.67 ps, which is too fast for common digital electronic technologies.

- *Geometrical* or based on triangulation (fig 2). Receiver is a linear or surface CCD. By using a lens, the spot of the laser beam, on the surface of the liquid, is focused on the CCD. This system allows a very simple circuitry, an easy calibration and is very stable with temperature. On the other hand, high sensitivity CCD is needed. Because the surface is not a fixed distance from the CCD (of course, this is the object of the measure), a self-focusing optical system has to be used. This implies electromechanical parts, which are not allowed in explosive atmospheres.
- *Phase-Quadrature Measurement Method.* In order to avoid the dependence between the amplitude of the signal at the receiver and the phase delay; two quadrature subcarriers may be used. Signals coming from the receiver are mixed with two local quadrature subcarriers. The output is then low-pass filtered. The block diagram of fig. 3 shows the practical implementation, where $\Delta\Phi$ may be calculated in [1]:

$$\Delta\Phi = arctang \frac{A\Theta_1 \, sen(\Delta\Phi)}{A\Theta_1 \, cos(\Delta\Phi)} \qquad (1)$$

This system lacks of the need of an extremely fine balance between the 0° and 90° branches. In the other hand, noise is not a main concern because, as we send a narrowband carrier, only a very narrow bandpass filter is needed.

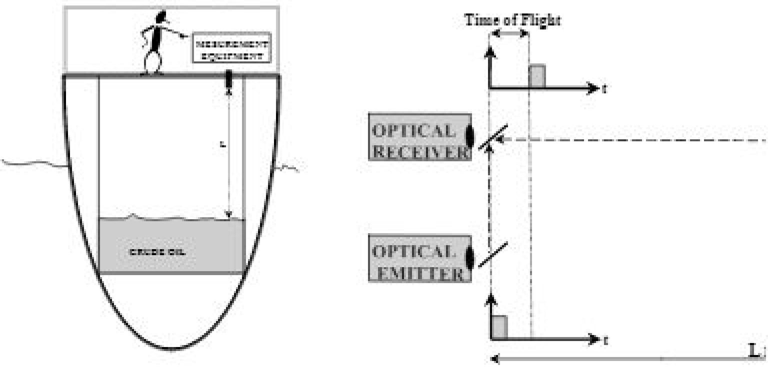

Figure 1. Time-of-flight based Measurement. Implementation with an optical wireless system

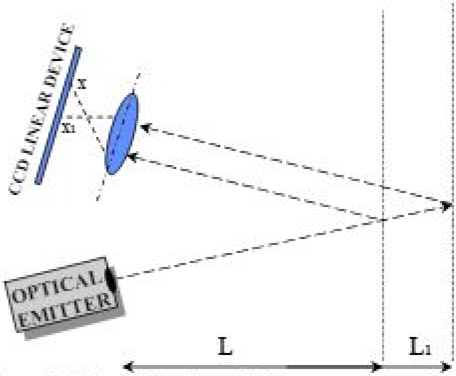

Figure 2. Triangulation-based Measurement procedure

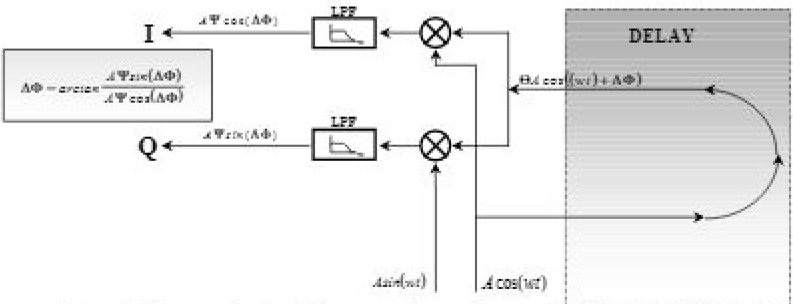

Figure 3. Phase-quadrature Measurement procedure practical implementation

2 BASIS OF SPREAD SPECTRUM SIGNALS APPLIED TO DELAY TIME MEASUREMENTS

The proposed system is based on calculating the cross-correlation between n replicas of the original signal, delayed n times T_c, and the received signal, after reflecting on the liquid surface. This correlation will be only positive for replicas with delay under the propagation delay. If this value is exactly a multiple of kT_c only one correlation will be positive. In other case, we will have two consecutive positive correlations.

For these two values, we can see that when one of them rises, the other one decreases. The ratio between both of them indicates the exact delay value. This delay, together with light speed, allows calculating the distance emitter-reflector-receiver. One half of this is the distance between emitter and the reflecting surface and indicates the liquid level of the oil tanker. We have used a

x^5+1 polynomial for code generation and chip rate is 40 Mhz. Process gain is then 36 dB.

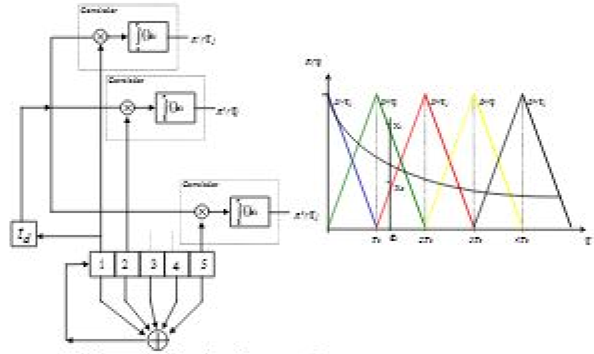

Figure 4. Basis of a spread-spectrum measurement system

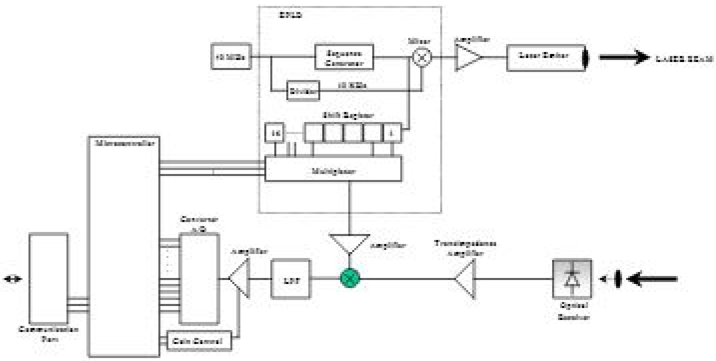

Figure 5. Block diagram of the spread-spectrum system

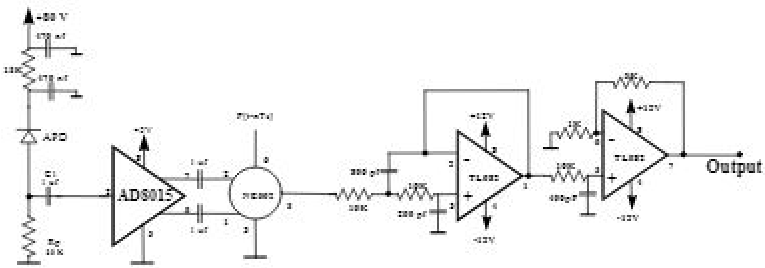

Figure 6. Optical receiver of the spread-spectrum system

3 RESULTS AND CONCLUSIONS

Figure 5 shows the block diagram of the measurement device. It is based in an ALTERA 7000 EPLD. Receiver (figure 6) uses an avalanche photodiode as a receiver, and then a transimpedance (AD8015) amplifier. Receiver signal at a distance of 5m. from the reflecting surface is –45 dBm (petrol has a reflecting coefficient of 0.15). We have measured distances with an error of ± 1 mm, (optical delays under 6 ps.).

This method offers a cheap and easy approach to the problem of the liquid-level measurement on an oil tanker. It can be implemented using inexpensive optical devices and offers more accurate resolution than classical time-of-flight or triangulation methods.

ACKNOWLEDGEMENTS

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