International Journal of Research in Engineering, Science and Management
Volume-2, Issue-4, April-2019
www.ijresm.com | ISSN (Online): 2581-5792

High-Resolution Level Gauge based on FMCW Radar

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***Abstract*: The fundamental measuring principle of FMCW (Frequency Modulated Continuous Wave) radar is used to achieve high accuracy. In this project we try to increase the accuracy of FMCW Radar based level gauge. By Changing gain and beam width parameters of antenna we can achieve better accuracy. Here the approach that we have chosen is – improving signal processing methods by choosing a perfect sampling rate. Phase evaluation along with beat frequency evaluation is a way in which we can ensure a more accurate measurement of the distance to be calculated. Pulse wave radar eliminates the option of phase evaluation and hence we cannot calculate the distance with utmost accuracy. So FMCW is the best option to calculate the depth of tank. This project has intense research in the initial stage. We have also researched and found out the basic outline for the radar front end and ADC-DAC. Certain complexities about signal processing like high frequency sampling, selectivity of data are also analyzed. We have chosen LAB-View software as best operational software that is compatible with high frequency ADC-DAC.**

***Keywords*: FMCW (Frequency Modulated Continuous Wave), Phase evaluation, Beat Frequency Evaluation, Frequency shift**

1. Introduction

In recent times, FMCW (Frequency Modulation Continuous Wave) are being widely used for the measurement of distance/range in a variety of industrial applications like automotive safety, level gauges, defense seekers, security etc. It is popular in most of the modern industrial plant for the measurement of bulk materials since the digital approach is more flexible and program updates are very easy. Here, our aim is to use a High frequency of 24-24.3 GHz FMCW radar so as to obtain a much better and accurate results. The current systems that have been deployed in the industries have been using a technology that gives a precision of about 2mm-3mm. The main focus of this project is to reduce that error of 2mm-3mm to about 0.05mm. The work for this project has been effectively carried out and the software simulation has been done and tested successfully.

Today's Market Product:

- Saab Tankradar PRO
- OPTIWAVE 8300 C Marine

So far the oil industries are using these products as the best available ones. These products have the major drawback of low accuracy (3mm-10mm) but they are the only products which are radar based non-contact measurement technology. There are contacting sensors and LVDT sensors available which perform poorly in conditions of moisture and harsh weathers.

2. Scope of the project

The biggest scope of the project is saving money that is lost due to not so precise measuring devices availability. The project focusses majorly on the fuel fields where there are very bulk fuels storage tanks. The future work for the project can been enhanced by focusing on designing of the product. By researching more on the designing aspects of each and every block of the system, the project can be re designed and also made compact and more potable.

Other things which can be taken into consideration is that digitizing the entire project. For example, the signal conditioning circuit which is designed here is complete analog, by using the various designing software we can design a digital signal conditioning circuit. In this way, we can define a software designed signal conditioning circuit. The benefit of this is that at such high frequencies at times it is impossible to find out the other noises and signals mixed with it, using software defined circuit the circuit will adapt itself according to the received signal. Thus betters the final product.

3. Proposed design

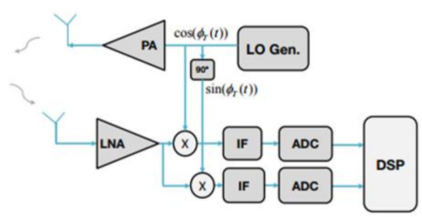

Fig. 1. Structural diagram of quadrature mixer

The block diagram shows the use of a quadrature mixer and complex-baseband architecture. In this case, the received signal mixes with the cos() and sin() versions of the LO, with a duplicated IF chain and ADC for the in-phase (I) and quadrature (Q) channels.

Quadrature Mixer: Two copies of the received signal are generated, one 90 degrees delayed with respect to the other, and these are separately mixed with transmitted signal. The output

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is two signals, viz. I and Q signals. They are samples of the same signal that are taken 90 degrees out of phase, and they contain different information. Higher frequencies are down-converted to lower frequencies.

4. Flow chart

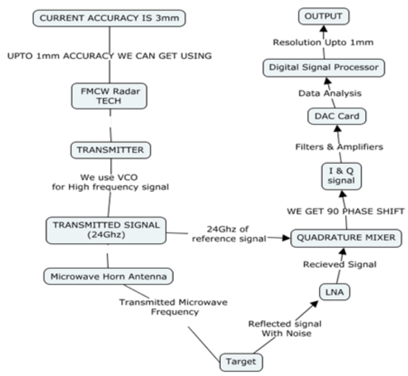

Fig. 2. Flow chart

A. Working principle

A high-frequency signal of 24GHz is first emitted using a radar in the proposed system. This signal after hitting the target gets reflected and the reflected frequency is captured by the system. A difference between the transmitted and the reflected frequency(Δf) is calculated and is transformed using Fourier transformation (FFT) for further calculations. The distance calculation is done on the basis of this difference a much accurate result is obtained.

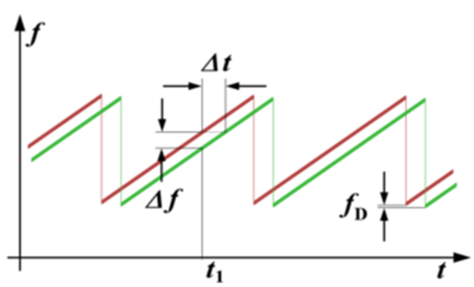

Fig. 3. Graphical representation of Transmitted wave and Received wave

Here, iD = c.lΔtl / 2
ii = c.lΔtl / 2.(df/dt)
Where,
c0 = speed of light = 3·108 m/s
Δt = delay time [s]
Δf = measured frequency difference [Hz]
R = distance between antenna and the reflecting object
df/dt = frequency shift per unit of time
The delay (Δt) is proportional to difference between the transmitted and received wave (Δf).

5. Hardware Components Required

The hardware being employed for such high-frequency circuit implementation are:

A. Gold plated high-frequency substrate

This substrate is specifically chosen so as the handle the 24-24.3GHz frequency. This substrate can withstand this high frequency with very minimal, Lowest electrical loss for reinforced PTFE material, Low moisture absorption, Isotropic, Uniform electrical properties over frequency, Excellent chemical resistance. Complete implementation of LNA (Low Noise Amplifier), Quadrature mixer circuit and SSC (Signal Conditioning Circuit) will be done on 20 mil (1 thousand of an inch) substrate which is able to handle such high frequencies.

F = F1 + (F2-1)/G1 + (F3-1)/G2*G1

The block diagram shows the use of a quadrature mixer and complex-baseband architecture. In this case, the received signal mixes with the cos() and sin() versions of the LO, with a duplicated IF chain and ADC for the in-phase (I) and quadrature (Q) channels.

B. Reflected Power Canceller

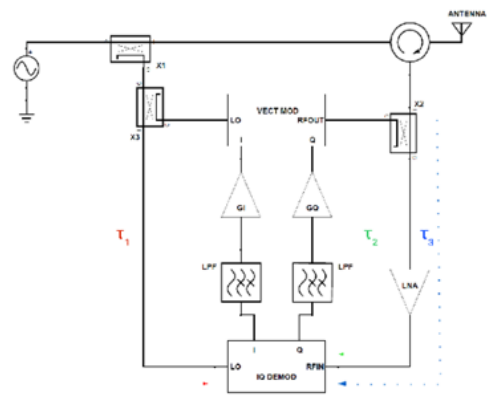

Fig. 4. Power canceller circuit

FMCW radar with single antenna causes leakage of transmitted signal into the receiver which can reduce the dynamic range and degrade the receiver sensitivity. One of the greatest challenges in designing continuous-wave monostatic radar lies in achieving sufficient isolation between the transmitter and the receiver. A novel adaptive reflected power cancellation technique in real-time digital signal-processing is proposed to nullify the transmitter leakage at the receiver front-end to achieve high isolation. With the digital implementation, the proposed scheme requires limited hardware and reduced logical elements than the previously reported adaptive digital implementations.

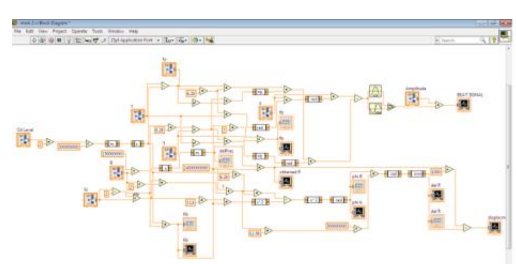

Fig. 5. Circuit diagram for evaluation of signal

6. Results

The entire system is been simulated in the LabView software for all the parameters that can affect the precision. Different parameters and their constraints were addressed with the single aim of degrading errors in the measuring system. The system on simulation gives the output of 0.05 mm. Currently, the hardware-based research is been done taking into account the various constraints of the hardware. The hardware designs for various blocks of the receiver system is been done for LNA, quadrature mixer and signal conditioning circuit.

The implementation of this high-frequency hardware is the biggest challenge of the project. Every minor parameter such as a substrate, environmental conditions, temperatures ranges for system functioning, heat sink, accessories, etc. is taken into account for selecting the materials for hardware implementation. Further, we will be using here is a horn antenna which is also under designing. And lastly, we are also currently on designing stage of Low Noise Amplifier (LNA). The LNA is designed for 24 GHz using p-HEMT.

A. VCO design

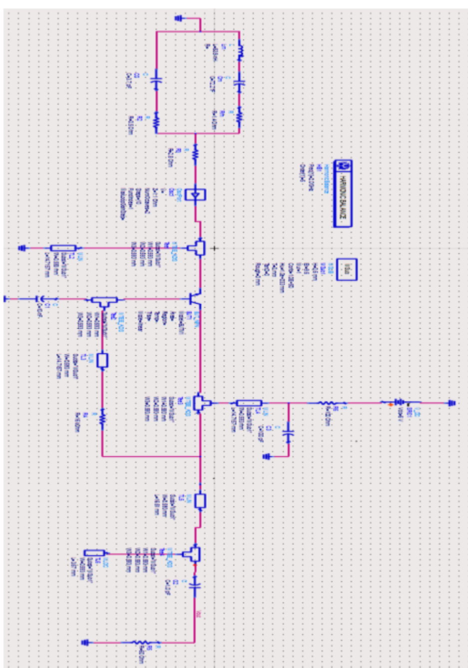

Fig. 7. VCO design

7. Conclusion

This paper presented an overview of high-resolution level gauge based on FMCW radar.

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