International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

LVDT Digital Demodulation Techniques

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ABSTRACT:

The Linear Variable Differential Transformer (LVDT) is a widely used electromechanical sensor for precise linear displacement measurement. Its operation is based on electromagnetic induction. This technology converts linear motion into an electrical signal. allowing for accurate and reliable readings. Due to its high sensitivity and robustness. the LVDT is commonly employed in various applications. including aerospace. manufacturing. and automation systems. Where a primary coil is excited with an AC signal. inducing voltages in two secondary coils. The difference in these secondary voltages provides a highly accurate. contactless measurement of displacement. Due to its high resolution. reliability. and immunity to environmental factors. LVDTs are extensively used in aerospace. industrial automation. robotics. and biomedical applications.

As technology advances. the need for LVDTs has grown in applications requiring precise real-time position feedback in extreme environments. Traditional analog demodulation methods. such as rectification and peak detection. often suffer from signal drift. noise. and phase errors. reducing measurement accuracy. To overcome these limitations. digital demodulation techniques have become essential. These methods leverage signal processing algorithms to extract displacement information more accurately and efficiently. Digital demodulation ensures higher signal stability. improved noise immunity. and better adaptability for modern embedded systems. This study explores various LVDT demodulation techniques. highlighting the advantages of digital processing over conventional methods. The findings demonstrate how digital demodulation enhances LVDT performance in critical applications like rocket actuator control and precision engineering.

Keywords: LVDT, AD598 IC, AC, DC, RMS, LVDT Demodulation, Linear Variable Differential Transformer, Matlab, Lvdt Digital Demodulation.

INTRODUCTION

The Linear Variable Differential Transformer (LVDT) is a highly accurate and reliable electromechanical transducer used to measure linear displacement. It operates on the principle of electromagnetic induction. converting linear motion into a corresponding electrical signal. This technology is widely utilized in various applications. including industrial automation. robotics. and aerospace engineering. due to its ability to provide precise measurements in challenging environments. It operates based on the principle of mutual inductance. providing a means to convert linear motion into an electrical signal. The LVDT is widely employed in industries where precise position sensing and control are essential. such as manufacturing. aerospace. civil engineering. and medical applications.

The core structure of the LVDT consists of three main components: a primary coil and two symmetrically placed secondary coils. And a movable ferromagnetic core. The primary coil is energized with an alternating current (AC). Creating an alternating magnetic field that induces voltages in the secondary coils. The secondary coils are connected in series opposition. Meaning their outputs cancel out when the core is at the neutral or central position.

As the core moves linearly within the coil assembly. the magnetic coupling between the primary and secondary coils changes. This results in a differential output voltage proportional to the core’s displacement. The polarity of the output voltage indicates the direction of displacement. This non-contact measurement method ensures no mechanical wear and tear. Making the LVDT highly durable and reliable for long-term use.

One of the key features of the LVDT is its exceptional accuracy and linearity. enabling the measurement of minute displacements with high resolution. Additionally. its rugged construction allows it to perform well in harsh environments involving high temperatures. vibrations. or contamination. The device is also versatile. with measurement ranges varying from a few microns to several inches.

Despite its numerous advantages. The LVDT has some limitations. It requires an AC excitation source and may exhibit temperature sensitivity due to the material properties of the core and coils. However. these challenges can be addressed with proper signal conditioning and compensation techniques.

The LVDT has found widespread application in fields requiring precise and robust displacement measurements. In industrial automation. it is used to monitor and control machine tool positions. actuators. and assembly line components. In aerospace. LVDTs are integral to flight control systems. landing gear monitoring. and structural testing. In civil engineering. they are employed in structural health monitoring systems to measure deflections. cracks. and subsidence in infrastructure. In the medical field. they are used in prosthetics. robotic surgery. and other advanced devices.

In summary. the LVDT is a cornerstone of displacement measurement technology. offering unmatched accuracy. durability. and reliability. Its robust design and adaptability have made it indispensable in modern engineering and scientific applications. As industries continue to evolve. the demand for precise measurement tools like the LVDT will only grow. Its versatility not only enhances existing technologies but also paves the way for innovative solutions across various fields.

AIM

The demodulation process in an LVDT converts the modulated AC output signal into a usable DC signal proportional to displacement. This process involves excitation. signal conditioning. rectification. and filtering. Currently we are using the AD598 IC for LVDT demodulation. The AD598 is a dedicated LVDT signal conditioning IC that simplifies excitation. demodulation. and signal processing. It generates the excitation signal. processes the secondary outputs of the LVDT. and provides a DC output voltage or current proportional to displacement. This integrated approach not only enhances the accuracy of the measurements but also reduces the complexity of the overall system design. Additionally. the AD598 offers features such as temperature compensation and noise reduction. making it a reliable choice for various industrial applications.

Our aim is to replace AD598 with a digital demodulation method. By comparing several methods. we came up with a method that is more accurate.

2. METHODOLOGY

The signal generation process begins with a 3 kHz sinusoidal carrier signal having an RMS amplitude of 7 V, which is equivalent to a peak amplitude of $7\times\sqrt{2}$ V. A low-frequency sinusoidal message signal, Representing displacement, Is generated with a frequency of 10 Hz and an amplitude of 3 V. To ensure high-resolution signal processing. A time vector ranging from 0 to 0.1 seconds is used. With a step size of 1 microsecond. Corresponding to a sampling frequency of 1 MHz. In the amplitude modulation stage, Two modulated signals. Va and Vb. are created to encode displacement information. These signals are generated by adding and subtracting the message signal from the carrier amplitude and then multiplying by a sinusoidal carrier wave. Mathematically,
This is represented as:

Va = (Carrier Amplitide + Message Signal).Sin(2π.Carrier Frequency.t)
Vb = (Carrier Amplitide - Message Signal).Sin(2π.Carrier Frequency.t)

These two signals serve as the primary outputs of an LVDT system, where their differential processing enables accurate displacement measurement. This precision is crucial in various applications, ranging from industrial automation to aerospace engineering. By analyzing the phase and magnitude of these signals, engineers can achieve high-resolution readings that enhance system performance.

Here, Vab is generated by subtracting Va and Vb, i.e.,

Vab = Va – Vb

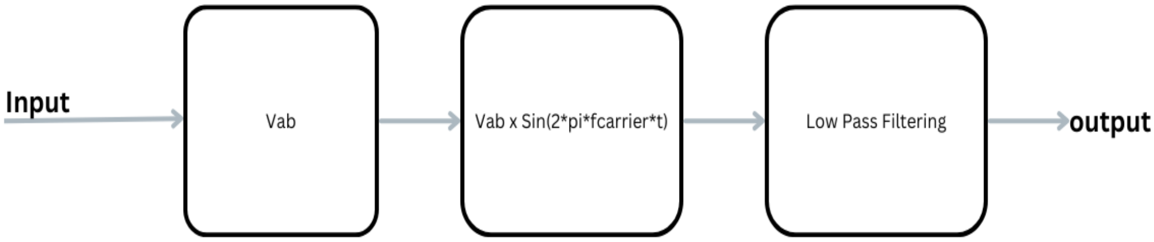


Figure1 Block Diagram

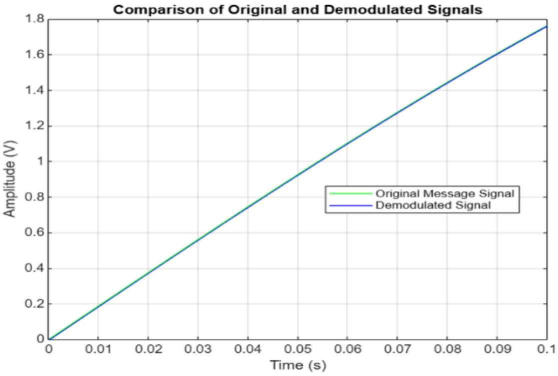
STEPS:

1. Input: The amplitude-modulated signal from the LVDT. Containing both the carrier and the displacement information.

2. **Multiplication (Vab×sin(2πfcarriert))**: This operation shifts the frequency spectrum of the signal down. centering the message signal at 0 Hz while creating high-frequency components around 2fcarrier. The result will include the baseband (message) signal and a double-frequency component.

3. Lowpass Filtering (Moving Average Filter): The moving average filter will smooth the signal. Effectively removing the high-frequency component at 2fcarrier. Leaving only the baseband message signal. Ensure that the cutoff frequency matches the range of the message signal (e.g.. 50 Hz if that is your message signal frequency).

3.OBSERVATIONS



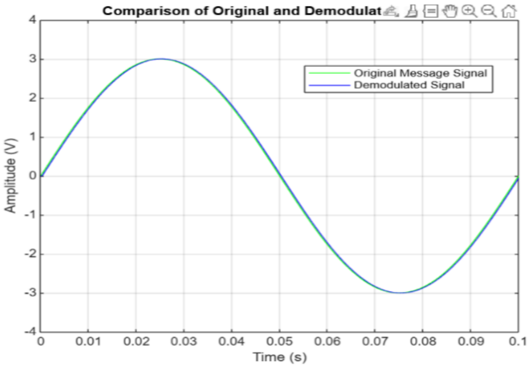


Figure 2: 1 Hz Plot

Figure 3: 10 Hz Plot

Here we have simulated the output using MATLAB software.We implemented each blocks in the block diagram in MATLAB. This MATLAB script simulates the demodulation process of an LVDT (Linear Variable Differential Transformer) signal. It begins by defining parameters such as the carrier frequency (3 kHz), Carrier amplitude (7 V RMS converted to peak) and a message signal (position-dependent) at 30 Hz. The LVDT secondary voltages (Va and Vb) are generated by amplitude modulation with the message signal. The differential signal Vab = Va - Vb is then computed. Which carries the displacement information. To extract the position-dependent signal, product demodulation is performed by multiplying Vab with the carrier signal. Since the demodulated signal contains high-frequency components.A simple moving average filter with window 500 samples is used here for the filteration. The moving average filter will smooth the signal, effectively removing the high-frequency components, leaving only the baseband message signal. Ensure that the cutoff frequency matches the range of the message signal (e.g., 50 Hz if that is your message signal frequency). Finally, The script plots the original message signal. Differential LVDT output (Vab). And the final demodulated signal. Which represents the displacement information.

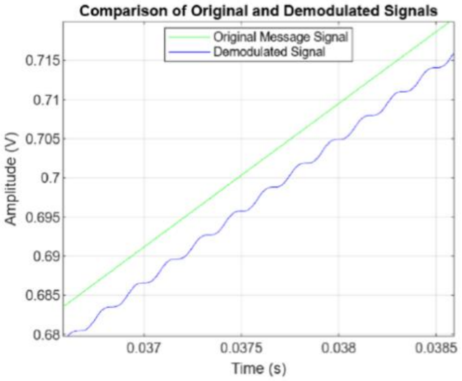


Figure 3: 10 Hz Plot

The figure 3 shows the direct comparison between the original signal and the demodulated signal. The original message signal and the demodulated signal differs only by a voltage difference of 0.005V.

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