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Designing a Schematic for Resolver and RDCInterface Validation

Manjunath Prakash Sajjan, Aditya Shyam Roshan
Electrical and Electronics Engineering, R. V. College of Engineering

***Abstract*—This paper presents the development of a specialized test rig for aircraft angle sensors, particularly those used in engines with thrust vectoring nozzles. The thrust vectoring nozzle enables gas flow acceleration and thrust direction adjustment. The test rig aims to assess the sensor's reliability and perfor-mance in simulated operational conditions. Key considerations include sensor specifications, environmental factors, and testing requirements. The rig incorporates rotational motion simulation and precise positioning, enabling comprehensive evaluation of thesensor's accuracy, functionality, and durability. Realistic aircraft scenarios, including extreme temperatures, vibrations, and electromagnetic interference, are emulated. The design features a robust framework, data acquisition system, and control interfaceto facilitate systematic and repeatable testing. This research aims to improve the quality and dependability of aircraft angle sensors, ensuring the safety and performance of critical systems. The outcomes of this study will further contribute to the field byadvancing the understanding of angle sensor performance in aircraft applications.**

***Index Terms*—Angle sensor, Resolver, Resolver-to-Digital Con-verter(RDC), Test-rig**

I. INTRODUCTION

The aerospace industry is continuously advancing aircraft design and technology to enhance performance, maneuverability, and safety. An essential aspect of aircraft design is the integration of thrust vectoring systems, which provide precise control over thrust direction. These systems are crucial for optimizing maneuverability during takeoff, landing, and in-flight operations. Accurate measurement of thrust vectoring anglesis vital to ensure the proper functioning of these systems.To achieve this, angle sensors are employed in aircraft thrust vector nozzles. These sensors offer real-time feedback on the nozzle's orientation, playing a crucial role in maintaining stability, improving maneuverability, and enhancing overall aircraft performance. Therefore, the design and development of a reliable and precise test rig for evaluating angle sensor performance is of utmost importance.

The primary objective of this project is to design and develop a comprehensive test rig specifically tailored for assessing the performance and reliability of angle sensors used in aircraft thrust vector nozzles. This test rig will enable engineers and technicians to validate the accuracy and responsiveness of angle sensors before integrating them into aircraft systems. By ensuring the reliability of these sensors, the test rig will significantly contribute to the safety and efficiency of aircraft operations. The design of the test rig follows a multidisciplinary approach, integrating principlesfrom mechanical, electrical, and software.

II. MOTIVATION

Angle sensors play a critical role in thrust vectoring systemsby measuring the nozzle angle relative to the engine exhaust. However, several challenges can impact the accuracy and dependability of these sensors in thrust vectoring nozzles. These challenges include sensor drift, noise, mechanical degradation,calibration issues, compatibility problems, and cost considerations. Over time, sensor drift can occur due to environmental changes, leading to inaccuracies. Noise and interference can also introduce instability and imprecise readings. Mechanical wear and tear can negatively affect the performance of angle sensors, while calibration can be laborious and time-consuming. Integrating different sensors with the system may present compatibility issues. Furthermore, high-quality angle sensors can be costly, posing a significant financial factorin the overall design and implementation of thrust vectoring systems. To ensure precise and reliable operation, it is crucial to select high-quality sensors, conduct regular maintenance and calibration procedures, and employ appropriate measures to mitigate the impact of noise and interference.

III. OBJECTIVES

A. To design the schematic for RDC Circuit, Excitation-buffercircuit and Input filter circuit:

The design process encompassed creating the schematic diagrams for the Resolver-to-Digital Converter (RDC) Circuit, Excitation-buffer circuit, and Input filter circuit. These circuits were meticulously designed to facilitate precise resolution conversion, efficient signal amplification, and effective noise filtering. The schematic designs ensure the optimal performance and functionality of the system, enabling accurate signal processing and enhancing the overall reliability of the resolver-based system.

B. To integrate Excitation-buffer and input filter circuit for interfacing Resolver and RDC:

The integration process involved incorporating the Excitation-buffer circuit and Input filter circuit to establish the interface between the Resolver and Resolver-to-Digital Converter (RDC). The Excitation-buffer circuit ensured the provision of an appropriate excitation signal to the Resolver, while the Input filter circuit effectively filtered out unwanted noise and interference from the Resolver output. This integration facilitated seamless communication and accurate signal transmission between the Resolver and RDC, enhancing the overall performance and reliability of the system.

C. To develop a Printed Circuit Board for acquiring the signals from Resolver:

The development process focused on designing a Printed Circuit Board (PCB) dedicated to acquiring signals from the Resolver. The PCB layout was carefully crafted to accommodate the necessary components, including connectors, signal conditioning circuitry, and appropriate grounding techniques. By optimizing signal paths and minimizing interference, the PCB facilitated efficient and reliable acquisition of Resolver signals, ensuring accurate and consistent data for further processing and control applications.

IV.LITERATURE REVIEW

In recent years, as said in paper [1] the space industry has experienced a significant change mainly due to the incursionof private companies, which has shaken up the sector. This new situation allows for a reduction regarding the reliability of conventional instrumentation for space while reducing the development time and manufacturing volume. Consequently, even though it has been typical to use equipment that was previously tested in space, this could be the right moment to introduce new technologies due to the previously men- tioned reasons. One of the interesting technologies with great potential is the rotary sensor in applications with motors. Historically, the resistive potentiometer has been the most useddue to its simplicity and robustness; however, it has several drawbacks. Due to this, the aim of this paper is to identify an interesting rotary sensor.

In paper [2] High efficiency electrical machines are increasingly used in industrial and vehicular applications and servo control systems. Most of the mentioned machines are inverter driven permanent magnet motors. The performance of the PM machines is highly dependent on the performance of the motion control unit and especially that of the position sensor. The most common position sensors are Hall-effect sensors, optical encoders, and resolvers. Although the Hall-effect sensors are the simplest and the affordable ones, in many applications theiraccuracy is questioned by offset, temperature, noise and ageing effects. Therefore, in such applications, optical encoders and resolvers are the best choices. Although many engineers preferto use optical encoders, in polluted environments with high variation of temperature and mechanical vibrations they are not practical. In this essence, resolvers are the best candidates for the industrial and rough applications.

In paper [3] Conventional resolvers are synchronous genera-tors whose excitation winding is fed by an AC instead of a DCvoltage. Thus, prior resolvers have brushes and slip rings to feed their excitation winding located on their rotor; these are called brushed resolvers. To reduce the maintenance cost of brushless resolvers, noncontact rotary transformers (RTs) have been developed. The primary winding of the rotary transformeris located in a ferromagnetic core that is coupled to the stator of the resolver and fed from an AC voltage. Its secondary winding is located in a secondary core that is coupled to the rotor of the resolver. The induced voltage of the secondary winding is used to feed the excitation winding of the resolver. Although this type of brushless resolvers is typically used in industrial applications, some researchers believe that theuse of a rotary transformer increases the complexity of the resolver, which in turn decreases the mechanical reliability of the system. Hence, they propose the use of variable reluctance (VR) resolvers. In VR resolvers, both the signal and excitationwindings are located on the stator, and there is no windingon the rotor. Therefore, neither a rotary transformer nor slip rings are required. Resolver interfacing circuits play a crucial role in accurately converting the analog outputs of resolvers into digital signals compatible with modern electronic systems. This review aims to provide an overview of different resolver interfacing circuits and their characteristics, based on relevant research papers. One commonly used resolver interfacing circuit is the Resolver-to-Digital Converter (RDC). In their paper, ”A high-resolution resolver-to-digital converter withadaptive sinusoidal modeling” [4], Hui et al. present a high-resolution RDC utilizing adaptive sinusoidal modeling. The circuit employs a sigma-delta modulator for accurate and robust conversion of the resolver signals. The paper highlightsthe effectiveness of this approach in achieving high-resolution conversion. Another notable resolver interfacing circuit is the Resolver-to-Digital Converter with Built-In Excitation (RDC- E). In the paper ”A resolver-to-digital converter with a built-in excitation signal generator for a resolver angle sensor”[5], Xu et al. propose an RDC-E circuit that integrates the excitation signal generation and conversion functions. Thecircuit simplifies system design and reduces external component count while ensuring accurate resolver signal conversion.Resolver-to-Pulse Converter (RPC) circuits offer an alternaive approach for resolver interfacing. In their study, ”High- resolution digital resolver-to-pulse converter based on pulse position modulation” [6], Wang et al. present a high-resolution RPC utilizing pulse position modulation. The circuit achieves accurate conversion through precise timing control and interpolation techniques. The paper highlights the advantages of this approach, including high resolution and compatibility withdigital systems. Resolver-to-Sine/Cosine Converter (RSCC) circuits directly convert the resolver’s sine and cosine signals into digital representations. In ”Digital resolver-to-sine/cosine converter with a field-programmable gate array” [7], Yanget al. propose an RSCC circuit implemented on a field- programmable gate array (FPGA). The circuit utilizes lookup tables and interpolation techniques to achieve accurate and real-time conversion. The paper demonstrates the effectiveness of the proposed circuit in terms of accuracy and speed.

V.METHODOLOGY

The methodology for designing a schematic and developinga PCB for resolver and RDC interfacing involves several steps as shown in Figure 1. First, conduct a thorough requirement analysis to understand the specifications, performance criteria, and constraints of the resolver and RDC interfacing circuit. Next, perform a comprehensive literature review to gather knowledge about existing resolver and RDC interfacing circuits, their design approaches, and relevant components. Basedon the requirements and literature review, start the schematic design by selecting appropriate components, including the resolver, RDC and other supporting elements such as filters, amplifiers, and power management. Utilize schematic design software to create a detailed circuit diagram, ensuring proper connections, signal conditioning, and noise reduction measures. Simulate the schematic using simulation tools to verify its functionality, accuracy, and performance. After finalizing the schematic, proceed to PCB design by converting the circuit diagram into a PCB layout. Consider factors like component placement, signal routing, ground planes, and thermal management for optimal performance. Utilize PCB design softwareto create the layout, ensuring adherence to design rules and specifications. Once the PCB layout is complete, perform design rule checks and simulate the board for signal integrity. After verification, generate the necessary manufacturing files and collaborate with a PCB fabrication and assembly serviceto produce the physical PCB. Conduct thorough testing and validation of the fabricated PCB to ensure its functionality andperformance align with the design requirements.

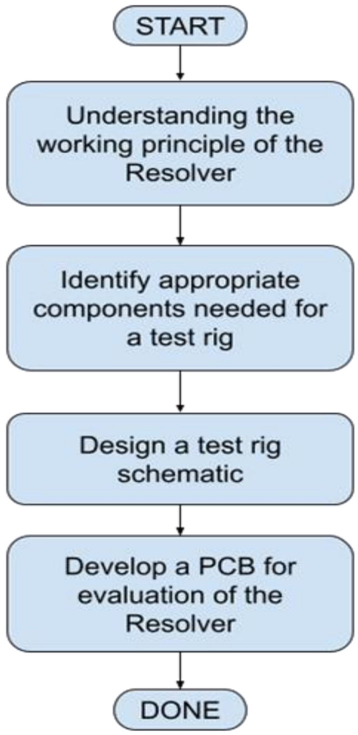

Fig. 1. Design Methodology

VI.SCHEMATC DESIGN

Designing a schematic for RDC and resolver interfacing involves selecting the appropriate resolver and RDC compo- nents and ensuring their proper connection. The resolver's primary and secondary windings are connected to the RDC inputs for accurate signal acquisition. Signal conditioning circuits, including amplifiers and filters, enhance the quality of the resolver's analog outputs. An resolver-to-digital converter (RDC) is incorporated to convert the analog signals into digital data. Proper grounding, noise reduction techniques,and component placement are crucial for reliable and accuratesignal acquisition.

A. Excitation Buffer Circuit

The excitation buffer circuit shown in Figure 2 in a Resolver-to-Digital Converter (RDC) plays a crucial role in ensuring accurate and reliable angle measurement. The pri- mary function of the excitation buffer circuit is to providethe appropriate excitation signals to the resolver, which is an electromagnetic device that converts mechanical anglesinto electrical signals. The excitation signals are typically sinusoidal voltages applied to the stator windings of the re- solver. The excitation buffer circuit consists of an amplifier and filtering components to generate a clean and stable excitation signal. The amplifier amplifies the excitation signal to the required voltage level, ensuring sufficient power is delivered to the resolver windings. The filtering components help eliminate unwanted noise and disturbances that can affect the accuracy of the angle measurement.

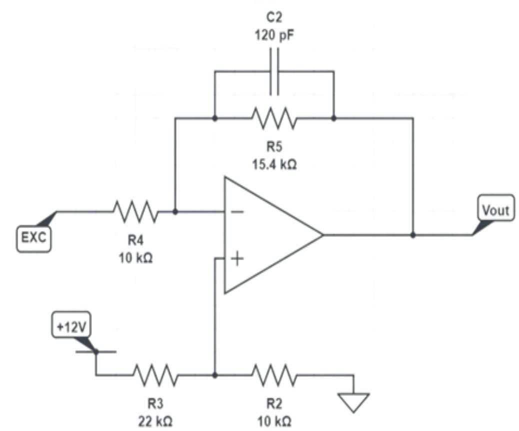

Fig. 2. Excitation Buffer Circuit

It is crucial for the excitation buffer circuit to provide a precise and stable excitation signal to the resolver. Any varia- tions or distortions in the excitation signal can introduce errorsin the angle measurement, leading to inaccurate readings. Therefore, careful design and selection of components, such as high-quality amplifiers and appropriate filtering elements, are necessary to ensure the excitation signal is robust andfree from noise. In addition to generating a clean excitation signal, the excitation buffer circuit also has power efficiency and thermal management.

B. Input Filter Circuit

The input filter circuit in a Resolver-to-Digital Converter (RDC) is an integral component that helps ensure accurate and reliable angle measurement. Its primary function is to suppress unwanted noise and interference from the resolver's output signals, allowing for clean and precise signal acquisition. The input filter circuit typically consists of passive components, such as resistors, capacitors, and inductors, strategically placed to attenuate undesired frequencies while allowing the desired resolver signals to pass through. The filter circuit is designed to have a specific frequency response that targets the noise frequencies and minimizes their impact on the angle measurement. The design of the input filter circuit requires careful consideration of the resolver's frequency range, the desired signal bandwidth, and the noise characteristics specific to the application. The selection of filter components and their valuesshould be based on these parameters to achieve optimal noise rejection while preserving the integrity of the resolver signals.

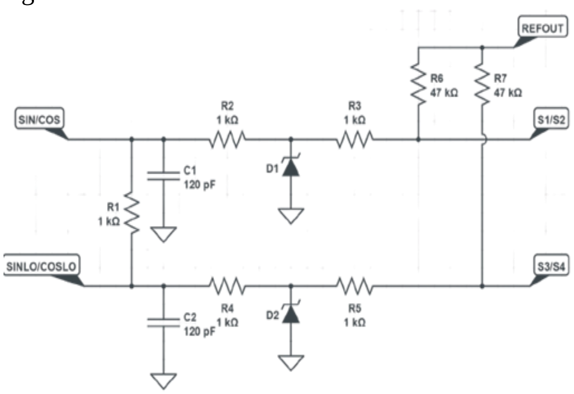

Fig. 3. Input Filter Circuit

The input filter circuit depicted in Figure 3 is a crucial ele- ment in achieving accurate angle measurement by mitigating noise and interference. Its design and implementation must be carefully tailored to the specific application requirements, providing robust filtering capabilities to ensure reliable and precise angle sensing in a wide range of applications.

C. Configuring RDC Circuit

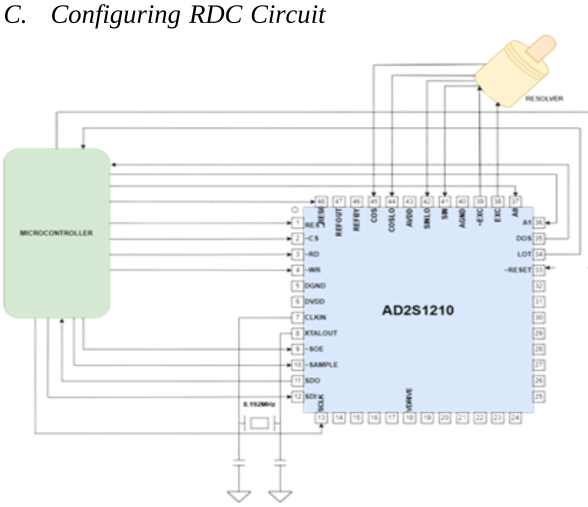

Fig. 4. Configuring RDC Circuit

Configuring the RDC with a microcontroller circuit involves establishing communication and data exchange between the RDC and the microcontroller. Initially, the microcontrollershould be selected based on the specific requirements of the application, taking into account factors such as processing power, communication interfaces, and compatibility with the RDC. The microcontroller should be programmed to communicate with the RDC using the appropriate protocol, suchas SPI or I2C. The necessary software routines and libraries should be developed or utilized to enable data transmission, configuration, and control of the RDC. The microcontroller circuit should incorporate the required interface connections, such as GPIO pins or dedicated communication ports, to establish a seamless connection with the RDC. Proper signal conditioning and level shifting techniques may be necessary to ensure compatibility between the microcontroller and RDC voltage levels. Once the microcontroller circuit is configured, the RDC can be controlled and monitored using the microcontroller, enabling integration into larger systems and facilitatingthe utilization of the RDC's features and functionalities.

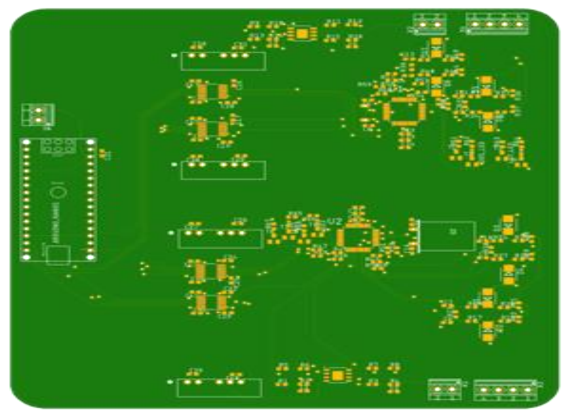

Fig. 5. PCB Routing

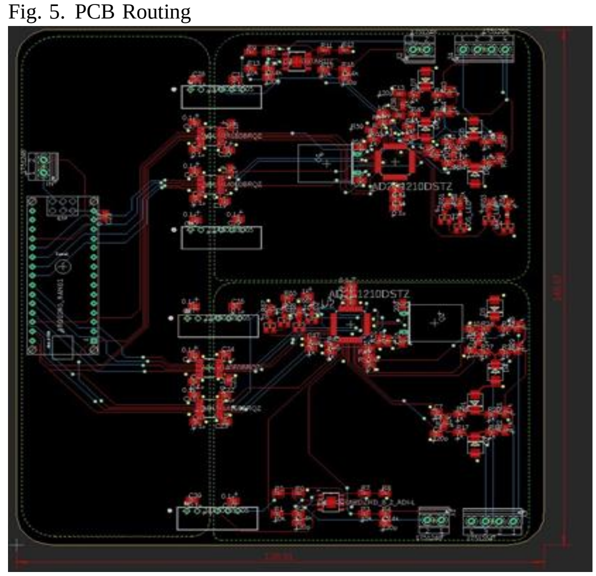

Fig. 6. PCB Board

Designing a PCB for the previous schematic involves translating the circuit diagram into a physical layout shownin Figure 5. This process includes selecting the appropriate software such a Eagle Autodesk, placing components, routing traces, and ensuring signal integrity and thermal management. Following design guidelines and best practices, the final step involves generating manufacturing files and collaborating with a PCB fabrication service to produce the physical PCB for testing and validation. the Final Printed Circuit Board is shown in Figure 6 with all the design specifications.

VII.RESULTS

Simulation results of RDC resolver interfacing with sine andcosine waveforms provide valuable insights into the accuracy and performance of the circuit. The simulation involves ap- plying ideal sine and cosine waveforms to the resolver inputs and observing the corresponding digital outputs generated by the RDC. The simulation results demonstrate the RDC's ability to accurately convert the analog signals into digital representations. Key parameters evaluated include resolution, linearity, and phase accuracy. The simulation allows for assess-ing the impact of noise, interference, and non-idealities on the performance of the resolver interfacing circuit. By comparing the simulated digital outputs with the expected values, the simulation results can validate the functionality and reliability of the RDC resolver interfacing circuit. Additionally, the simulation can aid in fine-tuning the circuit design, optimizingparameters, and identifying potential issues or limitations. Ultimately, the simulation results provide crucial information for further refinement and implementation of the RDC resolverinterfacing circuit in real-world applications.

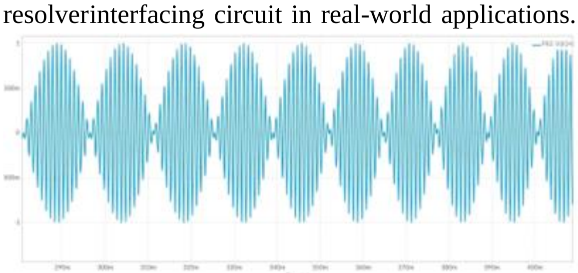

Fig. 7. Simulation result : Sine component

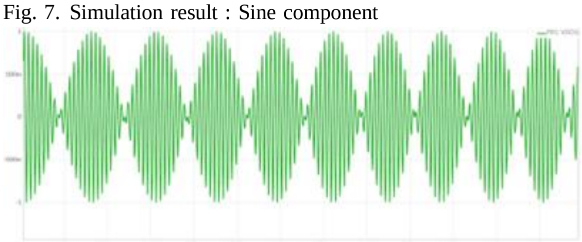

Fig. 8. Simulation result : Cosine component

Sine and cosine waveforms from a resolver provide angular position information. By analyzing the amplitudes and phase difference between these waveforms, the resolver's angle can be calculated. This angle data is crucial for precise position sensing and control applications.

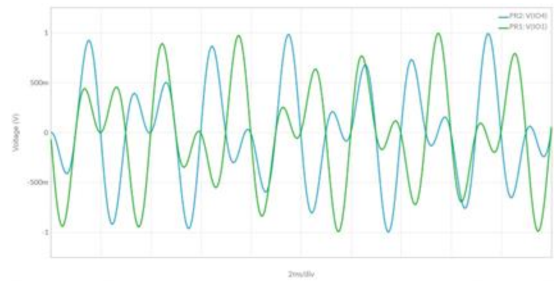

Fig. 9. Simulation result : Amplitude mismatch Sin-Cos signals

The calculation of the angle using the amplitude mismatch of the sine and cosine signals from the resolver involves analyzing the relative amplitudes of the two waveforms shownin Figure 9. By comparing their amplitudes, the angle canbe determined based on the known relationship between the amplitudes and the corresponding angle of the resolver's rotational position.

VIII.CONCLUSION AND FUTURE SCOPE

The design and development of a test rig specifically tailoredfor interfacing resolvers and RDCs in aircraft have significant implications for enhancing the reliability and performance of angle sensors used in critical aircraft systems. The test rig ensures comprehensive evaluation of the sensor's functionality,accuracy, and durability under simulated operating conditions. By incorporating features that emulate real-world scenarios en-countered in aircraft, such as extreme temperatures, vibrations, and electromagnetic interference, the test rig provides a reli- able platform for systematic and repeatable testing procedures. The outcomes of this research contribute to improving the quality and reliability of angle sensors, ultimately enhancing the safety and performance of aircraft systems.

Further advancements can be made in the test rig design to accommodate emerging technologies and evolving sensor requirements. Integration of advanced data acquisition and analysis techniques, such as machine learning algorithms, can enhance the test rig's capabilities in detecting and predicting sensor anomalies or failure patterns. Additionally, exploring the use of innovative materials and techniques for simulating extreme environmental conditions will enable more accurate and realistic testing. Furthermore, the test rig can be expandedto support the testing and evaluation of other critical aircraft components beyond angle sensors, broadening its scope and applications in aircraft systems testing and development. Con-tinued research and development in this field will lead to im- proved testing methodologies and contribute to the continuous improvement of aircraft safety, reliability, and performance.

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