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# LINEAR MODULAR CALIBRATION RIG FOR SAR PANEL

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**Abstract:** *Current solution for calibrating and testing of Synthetic Aperture Radar (SAR) is using small aircraft. This procedure wastes time and resources. In addition, aircraft does not provide reproducible conditions. The aim of this research is to develop a stable system which can be used for SAR calibration and testing on the ground to save resources and reduce time used for this procedure. A modular system was developed that enabled reduced vibration motion and accurate measurements. The vibrations of the developed rig were less than the baseline measurements (aircraft tests). It was determined that the major source of high frequency/low amplitude vibrations was the electric motor and the frame structure caused low frequency/high amplitude vibrations.*

*Key words: Synthetic Aperture Radar, Vibration, Modular test rig*

## 1. INTRODUCTION

Synthetic Aperture Radar (SAR) is a microwave radar technology used to capture and reproduce images of landscapes and targets. The radar emits waves that are reflected from objects depending on their characteristics. Soft materials absorb some of the energy of the signal reducing the amplitude of the signal while harder ones reflect it almost unchanged. This signal can be visualized into pictures that can be further processed to reduce noise from individual images by combining data from multiple images. The non-optical nature of SAR imaging combines all weather operation and high resolution [1]. SAR panels are used by integrating them in airplanes and satellites [2]. To ensure the condition and correct way of operation, SAR panels need to be tested and calibrated.

Currently, for calibration and testing, SAR panels are mounted on small airplanes. This procedure is time consuming and costly. In addition, due to environmental variables airplanes do not provide reproducible conditions. There are two main different error sources related with SAR calibration on airplanes. The first error sources, such as baseline length and inclination, are not expected to change with time. The other set of sources are related to the data recorded during flight, e.g. attitude angles, aircraft position and vibrations [3]. The problem with reproducibility can be solved by using calibration methods based on so-called “sensitivity equations”. These sensitivity equations are used afterwards to filter out the disturbance in the gathered data caused by previously mentioned error sources and to serve as a datum for homing i.e. zeroing the exact location of SAR. In order to use this calibration method, the movements of the airborne calibration platform need to be recorded in an accurate manner. However, this method does not reduce the costs and time needed for calibration and testing. [3, 4]

The aim of this research is to develop a system which can be used for SAR calibration and testing on the ground to save resources and reduce time used for this procedure. It is desired that a minimum of correction and post processing be done on the output SAR signals to correct for errors. In order to successfully develop this kind of device for SAR calibration it is essential to be able to control important parameters such as position and speed of the SAR panel. In addition, the vibrations should be limited below the vibration amplitude of airborne calibration and testing. The distance between the SAR panel and the target used for calibration and testing (Y direction Fig. 1) should not vary more than 10 % of the wavelength used by the radar which is 30 mm. Other features for this product are modularity (i.e. varying length of linear movement), transportability, ease of assembly and disassembly and movement speed control for the SAR panels. Fig. 1 represents the setup for the calibration rig.

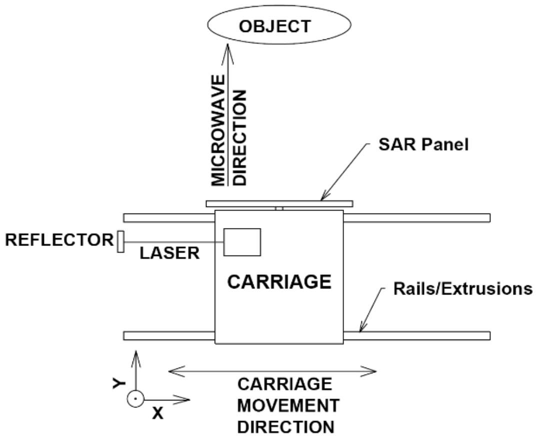
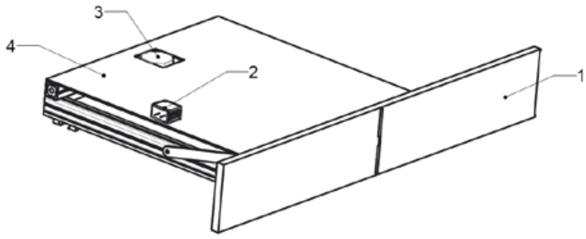



Fig. 1. Setup of calibration rig from top view.

## 2. CALIBRATION RIG

The base structure supporting the carriage and the linear roller rails is designed and made out of aluminum extrusion since aluminum profile systems provide the possibility to modify the system when needed without great development costs. [5]
The hull on the carriage is designed out of aluminum sheet and aluminum extrusions in a way that more levels can be added to increase the amount of installation surface. The carriage design and instrument placement is presented in Fig. 2). To ensure linear and stable movement for the carriage linear rails and rollers are used in this system. Rollers are preferred over linear ball bearings because the small ball bearings in the latter cause high pitch vibrations. [6] In addition, to provide smooth movement rollers can also carry a larger load over their linear ball bearing counterpart.




| | |
|---|---|
| 1 | SAR Panel |
| 2 | Laser |
| 3 | Stepper Motor |
| 4 | Cart |

Fig. 2. The carriage design and instrument placement

The linear movement and the power transfer is achieved by installing a 200 step/rev stepper motor on the carriage. The motor is installed on the base plate of the carriage and the power is transferred through a friction wheel to the aluminum extrusion. This solution enables modularity without increasing the number of components of the system (such as in a rack and pinion solution). To reduce vibrations in the system caused by high accelerations, acceleration and deceleration functionality was implemented to the stepper motor controller.
The relative distance in X direction needed by the SAR imaging unit is measured with laser class 1 laser distance measurement sensor using time of flight measurement method (Table 1).

| | |
|---|---|
| Wavelength | 658 nm |
| Frequency | 400 Hz |
| Repeatability | 0.5 mm |
| Accuracy | ± 3 mm |
| Range: | 0.2 – 50 m |

Table 1. Characteristics of the laser

The laser distance sensor was selected to achieve wide measurement range and stability against harsh environments and the distance measurement does not require any changes when the length of the base structure is changed. The laser distance sensor is installed on the carriage and a reflector at the other end of the system.

## 2.1. Operation principle

The carriage setup is presented in Fig. 1. The carriage moves linearly along the direction of the rails. The SAR panel is installed perpendicular to the direction of the movement facing the object.

The main operation principle of the test and calibration rig is presented in Fig. 3. The dashed line represents position data of the SAR carrier measured for the CPU. The system is not a closed loop driven system.

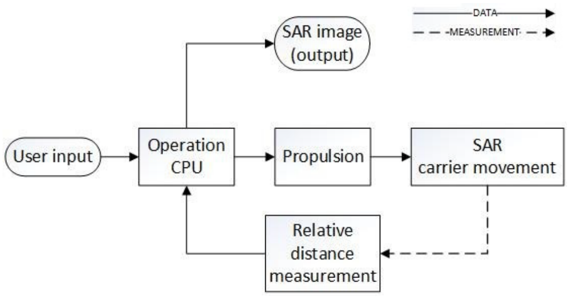



Fig. 3. Operation flow of the rig

The operation flow presented in Fig. 3 starts from the user input. In the first step user gives a desired command to the operation CPU. The control command given by the operator is the desired distance travelled at a desired speed.

The absolute position of the carrier is not important and thus the start and stop positions are irrelevant information. The relative distance measurement is used to trigger the SAR panel signals depending on the desired distance interval.

The SAR panel emits and receives radio waves during the movement. After the desired maneuver is completed, the operation CPU analyses and processes the received data in order to form an image.

## 2.2 Measurements

Vibrations and displacements are measured in Y direction (Fig. 1) at three different speeds, 0.10 m/s, 0.25 m/s, 0.35 m/s, and 0.50 m/s. The payload of the carriage on each measurement is set to 50 kg in order to simulate the real operating conditions of the calibration rig. The accelerometer is fixed on the SAR panel mount in Y direction. The vibration measurement setup is Bruel and Kjaer Nexus conditioning amplifier with piezoelectric acceleration sensor. The measurements are performed at 5 kHz measurement frequency.

## 3. RESULTS

Results of the Y-axis vibration measurements are presented in Figures 4, 5, 6 & 7. These figures represent vibrations in amplitude of acceleration versus time.

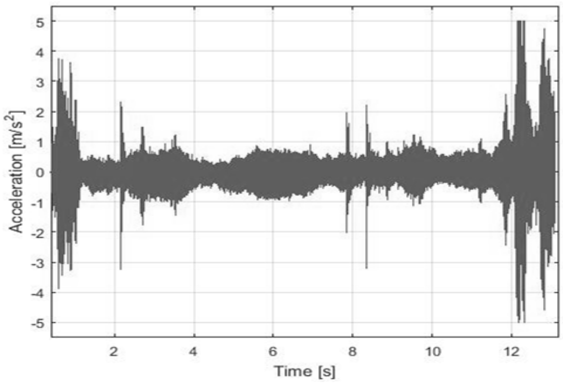



Fig. 4. Y-axis vibration measurement at 0.10 m/s.

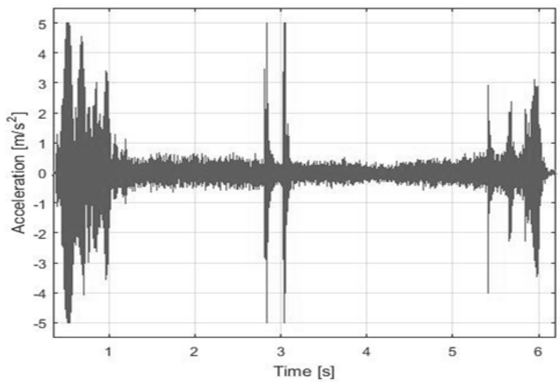



Fig. 5. Y-axis vibration measurement at 0.25 m/s.

Each figure shows three clear and distinct periods of time when the cart vibrates significantly more than during rest of the time.

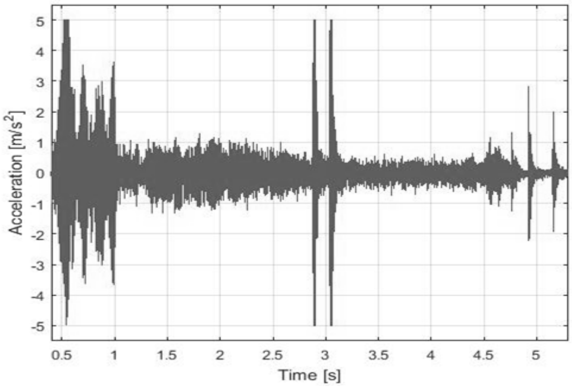



Fig. 6. Y-axis vibration measurement at 0.35 m/s.

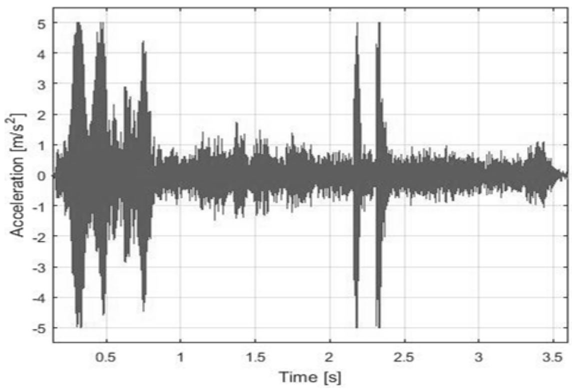



Fig. 7. Y-axis vibration measurement at 0.50 m/s.

The first difference occurs during the start acceleration of the cart. The second difference occurs when the cart passes the discontinuity point where two rail modules are joined. The final difference happens during deceleration of the cart. For example, on Figure 5 with target velocity of 0.25 m/s, first difference occurs between 0 – 1.2 s, second difference occurs between 2.7 – 3.1 s and the third between 5.4 – 6.1 s.

Vibration amplitude and duration caused by the start movement increases while the target velocity of the cart is higher. The same behavior of the vibrations occurs when cart passes discontinuity points of the rails. Opposite behavior occurs during deceleration of the cart.

During constant velocity and when not passing discontinuity points of the rails the vibration amplitudes are relatively low, stable and unexpected amplitude peaks do not occur.

## 4. DISCUSSION

Increased vibrations, due to higher target velocity, are caused by longer acceleration time needed to reach desired velocity. Similarly increased vibrations in discontinuity points are caused by higher movement speed. Decreased vibrations during deceleration at higher speeds result from property of stepper motors to vibrate at higher amplitudes at lower speed.

Due to higher vibrations during acceleration and deceleration of the cart, operating the SAR panel during these events is inadvisable. Signals received while passing discontinuity should be filtered out to improve uniformity and overall quality of the picture.

To develop calibration and testing system of improved quality, problems due to discontinuity points of the rails should be taken into consideration. This improvement ensures that higher percentage of the designed rail system can be used for calibration and testing purpose, thus increasing quality and uniformity of the acquired SAR image.

To further reduce vibrations of the system the stepper motor used in this setup can be replaced with a less vibrating motor type, however this is not required since the vibrations are low and predictable. In addition, more sophisticated vibration isolators, such as springs and special vibration dampeners could be added to the system between the vibration source and rest of the system.

The measurement results could be improved by implementing a rail system which has more accurate manufacturing tolerances and improved joints between each rail. In addition, measurements should be performed with longer system to better imitate real operation and testing conditions, thus providing better results.

The main goal of this research was to develop a calibration and testing rig for SAR panels to save time and resources spent on the calibration procedure. This goal was achieved. In addition, it was shown that it is possible to develop a sufficient calibration platform which surpasses the requirements set for the apparatus.

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