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Design and Implementation of Automated Rotatory Probe Embedded System for Measuring Axial Ratio

Hrishikesh Patel [(1)], Gaurav Seth [(2)], and Sanjay Trivedi [(3)]
(1) Nirma University, Ahmedabad
(2) Space Applications Centre, Ahmedabad

Abstract

The rotatory probe method used to determine axial ratio of Synthetic Aperture Radar (SAR) antenna widely employs manual systems. This study was aimed to minimize human efforts by automation of rotatory probe method of antenna to calculate axial ratio and validate circular polarization and full polarization transmitted from a SAR antenna. The approach towards automation of this method is achieved by 2-Way Handshake Communication Protocol. To develop this, a closed loop embedded system consisting rotating system and measurement system interfacing synchronously is implemented using serial communication. The interface between hardware components, microcontroller board (Arduino Uno), and software is established using two fundamental approaches: (i) Serial Port Communication between monitor and hardware and (ii) read and write .txt files using Read and Write functions as a parameter to send data and control bits. These computed data are used to determine microstrip antenna fabrication parameters used as a polarimetric SAR sensor.

1. Introduction

In a polarimetric Synthetic Aperture Radar (SAR) system, the Full Polarimetric (FP) mode is supposed to transmit horizontally (H) and vertically (V) polarized waves alternatively with relative phase difference of 0^o while the Hybrid Polarimetric (HP) mode is supposed to transmit horizontally (H) and vertically (V) polarized waves simultaneously with relative phase difference of 90^o [1]. Both these modes receive back coherently at the same time on both channels H and V (Figure 1).

To operate both FP and HP modes from the same system, individual programmable phase shifters are connected in both H and V chains. During ground characterization, the phase shifter settings need to be derived to maintain the relative phase difference for each mode (as shown in Figure 1).

Measuring the phase difference between the transmitted polarizations is challenging because the phase of the receiving antenna and instrumentation needs to be accurately characterized. As an alternative to measuring the phase difference, the axial ratio can be measured for different phase shifter setting combinations while transmitting both H and V polarizations simultaneously. Maximum axial ratio will correspond to relative phase difference of 0^o while minimum axial ratio will correspond to relative phase difference of 90^o.

To measure the axial ratio, a single port horn antenna is used. For each rotation step of the horn, the corresponding power is measured. After a full 360^o rotation, the axial ratio of the transmitting antenna is calculated.

An automated embedded system (AES) consisting of horn antenna, spectrum analyzer, motor driver, and controller was designed and developed to measure the axial ratio.

Section 2 of the paper describes its technique and methodology. The general test procedures of antennas are derived as per the IEEE standard protocols [2]. The developed system was verified by measuring axial ratio of waves transmitted from a helical antenna. Later the system was used to derive the phase shifter settings of full pol and hybrid pol modes of a SAR system by measuring axial ratio at different phase shifter combinations. Section 3 of the paper describes the results.

2.Technique/Methodology

2.1 Design and Development of an AES

2.1.1 AES outcomes

The overall aim of the AES was to design and implement the automation of power measurement at each degree of rotation of receiving horn antenna, which will be utilized to calculate axial ratio and generate radiation power pattern. In particular, the AES will perform the following:

- The receiving horn antenna rotates 0.9^o and records the power (dBm).
- After the received power value is measured and stored, the horn antenna takes the next step.
- The system calculates the axial ratio of transmitting electromagnetic waves and generates 2-D radiation power pattern.
- The system generates Real time plot of received power against its corresponding degree rotation in MATLAB software.

2.1.2 AES design

AES comprises the rotating and measuring systems. The rotating system includes the microcontroller software Arduino. Arduino continuously receives feedback from the measuring system. Depending on the feedback received, the microcontroller software will either generate and transmit a pulse to take next degree-rotation or wait until measurement process is accomplished. Figure 2.1 and 3.1 explains the setup and functioning algorithm of the rotating system at receiving horn antenna.

The measuring system includes Fieldfox N9916A Spectrum Analyzer (Keysight Technologies). When a degree of rotation occurs, the spectrum analyzer will note the power reading and store it. The measuring software MATLAB will continuously send feedback by writing either “GO” or “WAIT” in .txt file that is being read continuously. Figure 2.2 and 3.2 explains the setup and functioning algorithm of the measuring system at receiving horn antenna.

2.1.3 AES components and functioning

The system components and their functions are described in Tables 1 and 2. The types of polarization and corresponding axial ratios are shown in Tables 3 and 4, respectively.

2.1.4 AES considerations and troubleshooting

- The time delays need to be inserted in separate software codes to Synchronize serial port communication and hardware performing tasks. The timer should be timed out in case of any infinite loop execution and unavailability to fetch feedback.
- Arduino software has no library for creating files and the read/write functioning. Therefore, to establish a communication link between rotating system (Arduino code) and measuring system (MATLAB code), a “processing tool” software was introduced. The processing tool becomes the intermediate component between the rotating and measuring systems as it can operate both the tasks.
- The system must handle the problem of receiving “NULL” between transition from string “GO” to string “WAIT” as well as degree updates.
- During COM4 port serial communication, multiple transmission and receiving conflicts on the same port and therefore, serial monitor of Arduino software and Processing software cannot be operated simultaneously.

2.2 Core hardware of rotating system

2.2.1 Working of rotating mechanism and its control

In Arduino microcontroller system, a 2-pole switch was introduced to include the feature of direction control of receiving horn antenna. Figure 4 represents the configuration of Arduino microcontroller board, stepper motor driver, and stepper motor. Stepper motor driver TB6600 requires three digital control signals continuously from Arduino board to operate stepper motor NEMA 23 properly.

Three digital reference signal pins are EN+, DIR+, PUL+ connected to +5V pin of Arduino board.

- EN-: This digital Enable input of stepper motor driver will determine the mode of operation which is either using Arduino software or mechanically by pushbutton for an example.
- DIR-: This digital input determines the direction of rotation. Digital HIGH (>3.3 V) will implement clockwise direction and digital LOW (0-0.5 V) will implement anticlockwise direction.
- PUL-: Pulses generated in Arduino software code will be detected at this pin and according to that TB6600 will drive the NEMA 23 motor synchronously.

2.2.2 System features and control parameters: Speed and direction control

Partial Speed control:

- Since the system is closed loop and works on the feedback, total time taken to complete one rotation and calculation depends on components resource utility and efficiency. However, it can be varied by setting different delay time introduced in software codes.
- The average time taken by the system to rotate 360 degrees (complete rotation) is around 30 minutes.

Direction control:

- The direction is controlled by predefined pin in motor driver (-DIR).
- If the pin is Digital high, it is considered as clockwise direction and low for counter clock-wise direction. This is operated using 2-pole switch and software code.

3. Results

As helical antenna is used as a transmitting antenna, it generates circular polarization of electromagnetic waves and constant 2 dB axial ratio is achieved. This is shown in Figure 5. The axial ratios determined as a result of a successful AES implementation (Figure 6) are shown in Table 5. These results are currently used in polarimetric SAR antenna for future application.

5. Figures and Tables

5.1 Figures

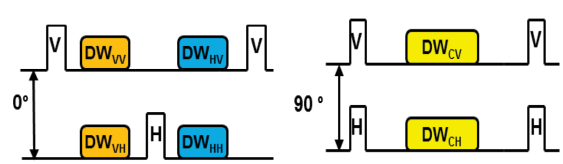

Figure 1. Transmission approach in FP Mode (left) and HP Mode (right)

RECEIVING ANTENNA-ROTATING SYSTEM

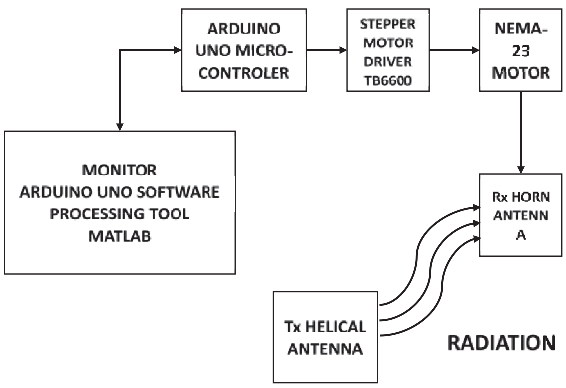

Figure 2.1 Hardware Setup and control/data flow of Rotating system at Receiving end.

RECEIVING ANTENNA- MEASURING SYSTEM

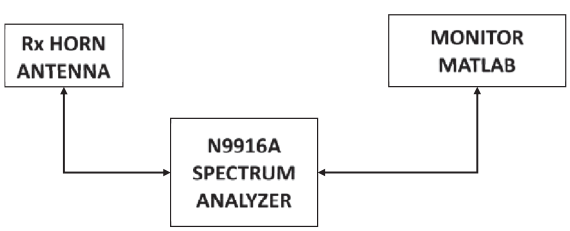

Figure 2.2 Hardware system configuration of Measuring system at Receiving end

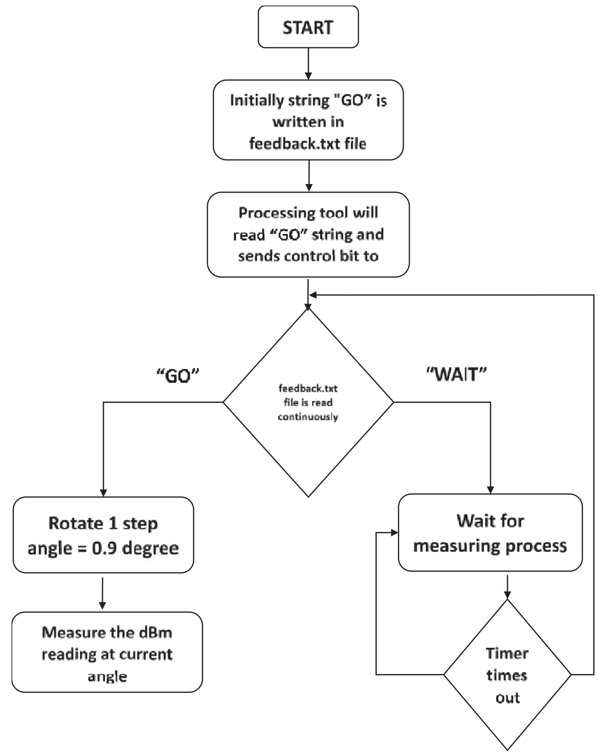

Figure 3.1 Flowchart explaining the mechanism of Automated Rotating subsystem

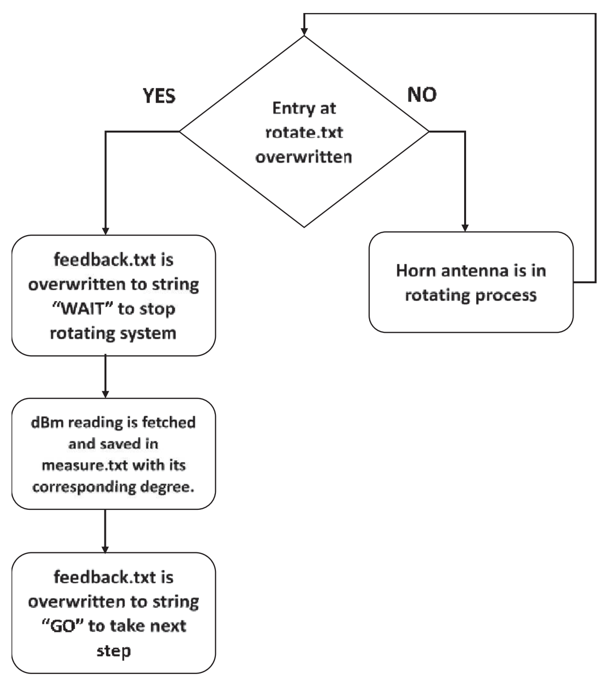

Figure 3.2 Flowchart explaining the mechanism of Automated Measuring subsystem

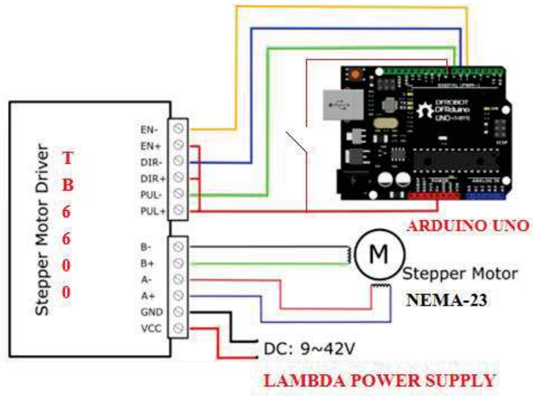

Figure 4. Circuit diagram of the hardware configuration to implement rotation of receiving horn antenna Arduino controls the rotating operation by sending control digital outputs to stepper motor driver through digital pins 5,6,7 and 9. Bipolar 4-wire NEMA 23 receives pulse train with A+, A- and B+, B-. pins of TB6600. Torque of NEMA 23 depends on the power delivered duration through

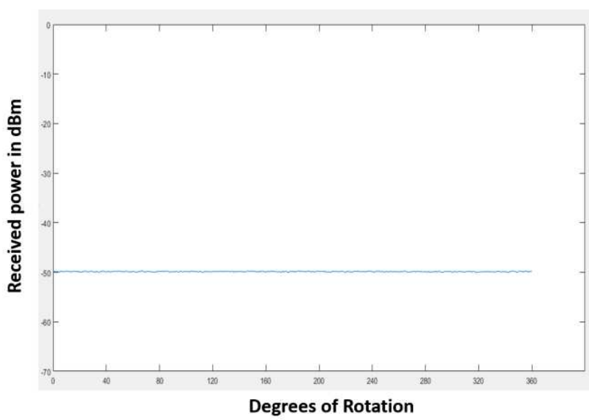

Figure 5. Measured axial ratio for a helical antenna

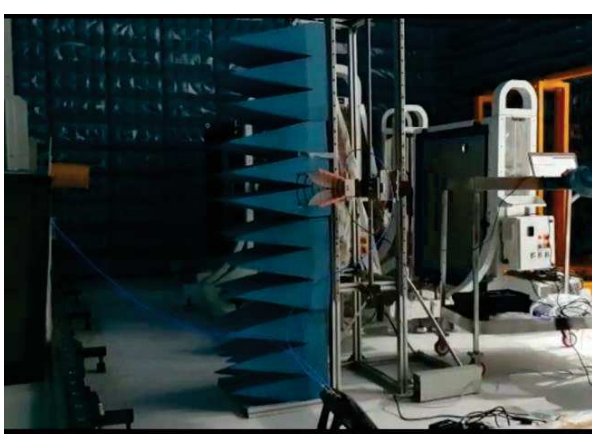

Figure 6. AES test-setup

5.2 Tables

Table 1. List of hardware components of Automated Embedded System

	Hardware Component	Function	Reference
1	Arduino Uno (Microcontroller Board)	Commands stepper motor driver according to monitor and system feedback	
2	Stepper Motor Driver TB6600	Drives stepper motor according to Arduino control signals	
3	Stepper Motor NEMA 17 or NEMA 23	Rotates Receiving Horn antenna mechanically connected/attached	
4	Fieldfox Spectrum Analyzer N9916A	Measures Received power in dBm and interfaced with monitor using SCPI	
5	TDK Lambda Power Supply	Voltage supply	
6	Helical Antenna (Tx antenna)	Test antenna for transmitting Circular Polarized EM waves	
7	Horn Antenna (Rx antenna)	Test antenna for accurate power pattern and axial ratio measurement	
8	LAN cable and SMA connector	Cable for Serial port communications and connects horn antenna to spectrum analyzer	

Table 2. List of software components of Automated Embedded System

	Software Component	Function	Reference
1	Arduino	Rotates Horn antenna by continuously receiving feedback control bits (‘0’ or ‘1’) to port(COM4)	

		Transmits new updated position of horn antenna (degree rotation) to port (COM4)	
2	Processing Tool	Receives new updated position of horn antenna through port and writes degree value in rotate.txt file Continuously Read feedback.txt file ("GO" or "WAIT") and send feedback control bits on port ("GO" = 0 & "WAIT" = 1)	
3	MATLAB	Continuously Read rotate.txt and takes measurements using SCPI only when degree value is updated Continuously Write ("GO" or "WAIT" strings) to feedback.txt according to the measuring time taken.	

Table 3. Types of polarization

Polarization	Phase-shift Angle (P)	Magnitude of E components
Linear	0^oor 180^o	unequal or equal
Circular	$+90^o$or -90^o	equal
Elliptical	-	unequal

Table 4. Axial ratio according to polarization

Polarization	Axial ratio
Linear	∞
Circular	1
Elliptical	$(1,\infty)$

Table 5. Axial ratio of a polarimetric SAR system

Sr. No	Phase Settings	Max Power	Min Power	Axial Ratio	
1	H5.625V0	26.2	20.34	5.86	
2	H16.875V0	25.53	21.29	4.24	
3	H22.5V0	25.53	22.08	3.45	
4	H28.125V0	25.2	22.94	2.26	
5	H33.75V0	25.01	23	2.01	
6	H39.375V0	24.59	23.61	0.98	
7	**H45V0**	**24.37**	**23.98**	**0.39**	**Hybrid Pol**
8	H50.625V0	24.77	23.46	1.31	
9	H56.25V0	25.1	22.97	2.13	
10	H67.5V0	25.2	21.5	3.7	
11	H78.75V0	25.84	20.77	5.07	
12	H95.625V0	26.51	18.18	8.33	
13	H106.875V0	26.69	15.83	10.86	
14	H118.125V0	26.84	14.94	11.9	
15	H129.375V0	26.94	2.8	24.14	
16	**H135V0**	**27.06**	**2.28**	**24.78**	**Full Pol**
17	H140.625V0	27	5.11	21.89	
18	H151.875V0	26.81	12.87	13.94	
19	H168.75V0	26.66	13.6	13.06	
20	H180V0	26.18	19.79	6.39	

6. Acknowledgements

We would also like to thank all the members of MRSA Department, SAC-ISRO for their cooperation.

7. Conclusion

The AES is a fundamental development in rotatory probe methods with improved precision and power efficiency, time saving, maximized resource utilization, and human-effort reduction. Using this output testing simulated data-readings, research on SAR backscattering matrix solving technologies can be improved and developed based on other algorithms.

8. References

1. B. Y. Toh, R. Cahill, and V. F. Fusco, “Understanding and measuring circular polarization,” *IEEE- Trans. on Education*, **46**, 3, August 2003, pp 313-318.

2. IEEE Std 149™-1979 (R2008), IEEE Standard Test Procedures for Antennas, IEEE standards board.