Design of Frequency Reconfigurable Patch Antenna for Sensing and Tracking Communications

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Abstract **─** This paper presents a front-end structure of a reconfigurable patch antenna for cognitive radio systems. The antenna structure consists of an Ultra-wideband (UWB) sensing antenna and an array of frequency reconfigurable antennas incorporated on the same substrate. The UWB and reconfigurable antennas are fed by co-planar waveguides (CPW). The reconfigurability is achieved by rotating the series of patch antennas through a certain angle and the rotation is controlled by mechanical means using an Arduino microcontroller. The rotational reconfigurability has been preferred over MEMS switches, PIN diodes, and other lumped elements because the latter requires the need for bias lines. The entire structure is designed using High Frequency Structure Simulator (HFSS) software and the prototype is fabricated over FR-4 substrate having a thickness of 1.6mm and measurements are carried out. This antenna achieves a wideband frequency from 2 GHz to 12 GHz and distinct narrow band of frequencies by reconfigurability using single antenna consisting of different shapes spaced accurately to ensure isolation between adjacent frequency bands and each antenna element working for a bandwidth of 2 GHz for frequency from 2 GHz to 12 GHz upon a single substrate and the reconfigurable elements are controlled using a low cost Arduino microcontroller connected directly to the antenna which ensures accurate controlling of the rotation and fast switching between the antenna elements. The measured results agree with the simulated results and have less than 10 dB impedance bandwidth.

Index Terms **─** CPW feed, mechanical control, reconfigurable antenna, sensing applications, tracking applications, UWB antenna.

I. INTRODUCTION

Cognitive radio (CR) is touted as the future of RF communication systems. It can be the perfect solution for spectrum scarcity and spectral traffic. According to the Federal Communications Commission (FCC), “a cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.” In order to change the transmission parameters, an antenna should have the ability to sense its vicinity. Hence a more generalized architecture for the CR system involves the use of a UWB sensing antenna and frequency reconfigurable antenna arrays. The UWB sensing antenna continuously monitors the spectrum to identify the spectrum with the least traffic (white spaces) and adjusts its transmission parameters to communicate in that spectrum. This dependency on the reconfigurable antennas has made it one of the hot topics for research. A large amount of work has been carried out in designing antenna structure for cognitive radio systems. The proposed design is inspired by [1] in which a CR system is implemented by incorporating both UWB sensing and reconfigurable antennas on the same substrate. The reconfigurability is achieved through the rotation. The proposed design varies extensively in terms of the design, material used and the technique of controlling the rotational movement. The antenna is

Submitted On: June 10, 2020
Accepted On: September 26, 2020
https://doi.org/10.47037/2020.ACES.J.351212

designed over an FR-4 substrate with a CPW feeding structure. This was preferred over a microstrip feed line as presented in [1] to enhance the bandwidth response considering a low-cost substrate material. Detailing of different types of reconfigurable antennas and different methods to achieve reconfiguration has been explained in [2]. Achieving frequency reconfigurability by providing DC bias through a RLC coupled DC line circuit is exploited in [3]. A polarization and frequency reconfigurable patch antenna in which the reconfigurability is achieved through mechanical rotation of the radiating element is explained in [4] and a frequency reconfigurable antenna achieved through rotation with 4 different shapes in [5].The challenges involved in designing a CR system and the general architecture of a CR system has been described in [6]. An Insight on the design approaches for a CR system is also presented. In [7], a combination of wideband and narrowband antennas designed over the same substrate is presented. The wideband antenna is a CPW fed printed hour-glass shaped monopole which operates from 3 to 11GHz. The narrowband antenna is a microstrip patch printed on the reverse side of the substrate and connected to the wideband antenna via a shorting pin and designed to operate from 5.15 to 5.35 GHz. Reconfigurability in frequency can be obtained either by making uses of switches (MEMS, LASER diodes) or by rotational motion. Many works have been carried out in both of these categories. In [8] the authors have used MEMS switches to switch on parts of the antenna structure enabling it to tune to frequencies between 5 and 7 GHz. [9] takes another approach by rotating the reconfigurable antennas by 180° enabling it to work in 4 GHz and 6.65 GHz. Saravanan and Rangachar [10-11], demonstrated reconfigurable antenna using pin diodes operating at S-band. Lin and Wong [12] presented a polarization reconfigurable antenna by reconfiguring feeding network through sequential excitation by means of pin diodes in the feed network. A most common method of achieving polarization reconfiguration is by etching a slot on radiating element and reconfiguring it by means of pin diodes [13]. Polarization diversity by bridging the slot gap with diode switches is achieved in [14].

II. ANTENNA STRUCTURE

The antenna is designed over an FR-4 substrate of dimension 100 × 60 × 1.6 mm^3 with a dielectric constant of 4.4. The antenna structure is shown in Fig. 1. It can be divided into two separate modules. The first being a UWB sensing antenna present at the left of the substrate and the next is an array of patch antennas placed inside a circle of radius 24 mm.

A. Wideband sensing antenna structure

The sensing antenna is a UWB sensing antenna fed by a CPW feed line. The UWB antenna takes the shape of a planar INVERTED C Antenna (PICA) as shown in Fig. 2. It uses a CPW feed having width of 4 mm and a gap of 0.3 mm between the microstrip line and the ground plane. This feed line ensures impedance matching at the ports (50Ω). The UWB sensing antenna has a bandwidth of about 10 GHz enabling it to scan an entire spectrum from 2─12 GHz.

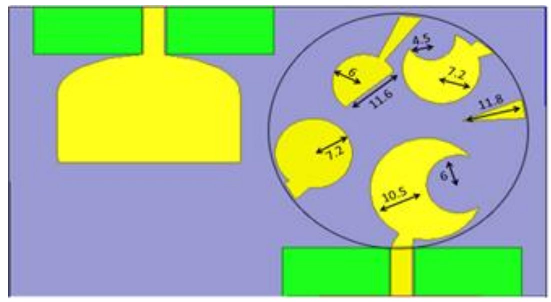


Fig. 1. Antenna structure.

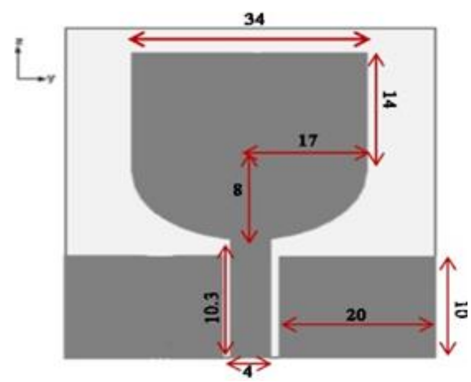


Fig. 2. UWB antenna structure (dimensions in mm).

B. Reconfigurable antenna structure

The reconfigurable antenna structure is designed to the right of the sensing antenna as shown in Fig. 1. It is sufficiently isolated from the sensing antenna by placing the input ports diagonally opposite to each other thereby minimizing the coupling between the two ports. The reconfigurable antenna was designed with proper tuning and spacing between each antenna element to ensure complete isolation and reduced coupling to avoid adjacent band interference. The arrays of patch antennas are placed inside a circle of radius 24 mm. The various patch antennas when rotated by a certain angle gets excited by the feeding system. Each patch resonates at certain frequency spanning across the entire spectrum as defined by the sensing antenna. A thick conductive lead is soldered to the feed line. The Arduino is programmed in such a way that the particular structure comes in contact with the feed for the respective angle of rotation. Initially the conductive element represented as shape 1 is at 0° which then rotated to an angle of 37° so that the shape 2 conductive patch comes in contact with the feed. Further by moving shape 2 by 37° using arduino microcontroller the shape 3 conductive element comes in contact with the feed point and start radiating. The Shape 4 conductive patch comes in contact with the feeding system by further rotation of shape 3 by 99° and the shape 5 comes into contact with feed after moving shape 4 at an angle of 60°. The initial position of shape 1 can be regained by further moving shape 5 at an angle of 127°. The various reconfigurable shapes with its angular positions are shown in Fig. 3.

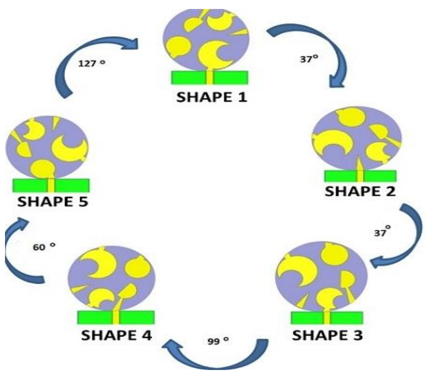


Fig. 3. Reconfigurable positions.

III. RESULTS AND DISCUSSION

The design is modelled and simulated in HFSS. The simulation results and its implication are discussed in this section.

A. Wideband sensing antenna

The UWB sensing antenna is designed as shown in Fig. 2. The performance of the UWB antenna is unaltered for any given position of the reconfigurable antenna. This is due to the fact that the antennas are sufficiently isolated by feeding them diagonally opposite to each other. The S_{11} curve of the wideband sensing antenna is measured using N3916A VNA and the measurement setup is shown below in Fig. 4. It is observed from the return loss plot shown in Fig. 5 that the UWB antenna operates from 2–12 GHz with a bandwidth of about 10 GHz.

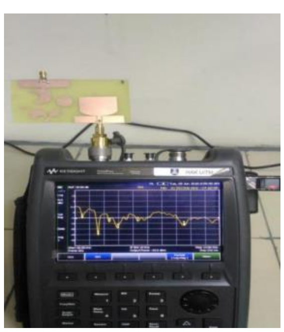


Fig. 4. Measurement setup of UWB antenna.

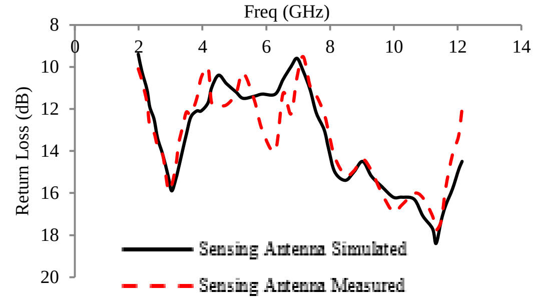


Fig. 5. Return loss - UWB sensing antenna.

The simulated radiation pattern of the UWB antenna for 6 GHz, 8 GHz, and 10 GHz in E-Plane are shown in Fig. 6. The radiation pattern is near omnidirectional over the entire spectrum.

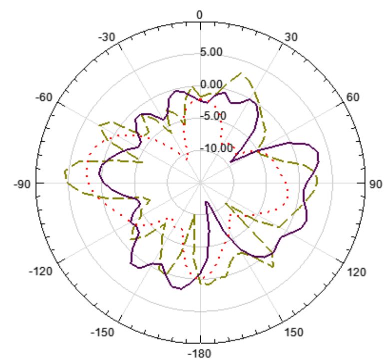


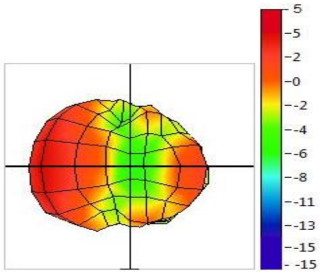
Fig. 6. Simulated UWB antenna radiation pattern at f = 6 GHz (dotted line), f = 8GHz (solid line), f = 10 GHz (dashed line).

The results in Fig. 7 show the measured 3D radiation pattern of the sensing antenna. Figure 7 (a) shows the measured radiation pattern at 6 GHz. Figure 7 (b) shows the radiation pattern measured at 8 GHz and Fig. 7 (c) shows the measured radiation pattern at 10 GHz.

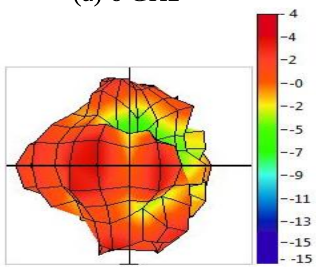
B. Reconfigurable antenna

The simulated and measured return loss with respect to the frequency of the reconfigurable antennas is shown in Fig. 8 (a) and Fig. 8 (b). It is observed from Fig. 8 that, each shape of the reconfigurable antenna corresponds to specific parts of the spectrum adding up to span across the entire UWB. The simulated and measured return loss characteristics shown in Figs. 8 (a) and 8 (b) shows a 10dB impedance bandwidth for all the frequency bands.

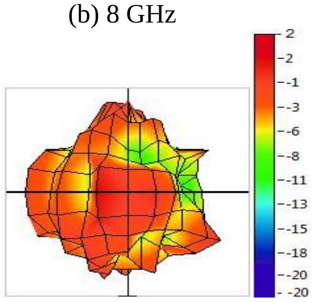
Figure 3 shows the various reconfigurable positions. Reconfigurability through rotation was preferred mainly because it doesn't need any external bias or optical pumping as in MEMS switches and laser diodes which are used conventionally. In the simulation, the reconfigurable antenna structure is rotated for the specified angle as mentioned in Fig. 3. The simulated and measured radiation pattern for the reconfigurable antennas is shown in Fig. 9 and Fig. 10 respectively. Table 1 gives the details, entailing each shape along with the gain of the reconfigurable antennas. Fig. 11 gives gain of the sensing antenna along the entire bandwidth.



(a) 6 GHz

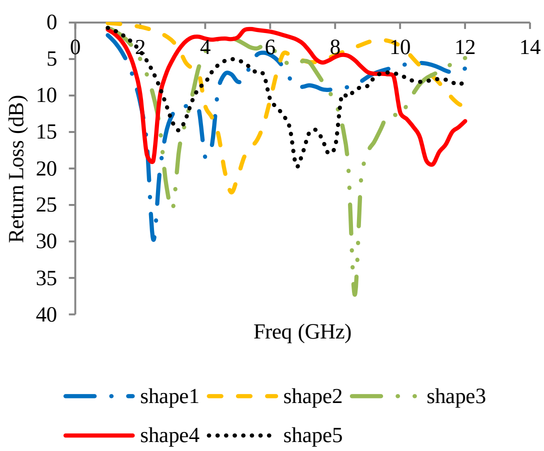


(b) 8 GHz

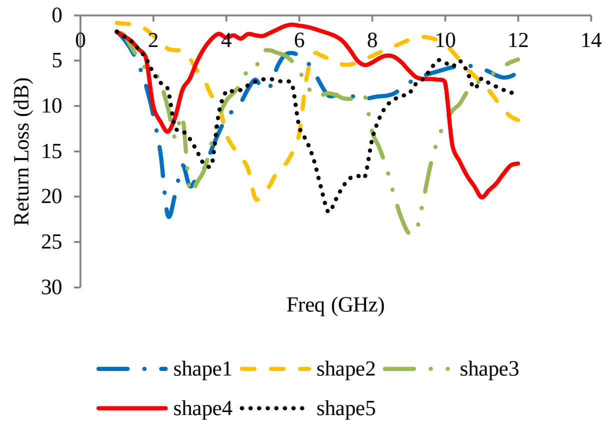


(c) 10 GHz

Fig. 7. 3D measured radiation pattern (UWB sensing antenna).



(a) Simulated return loss (dB)



(b) Measured return loss (dB)

Fig. 8. Return loss (dB) at different antenna shapes.

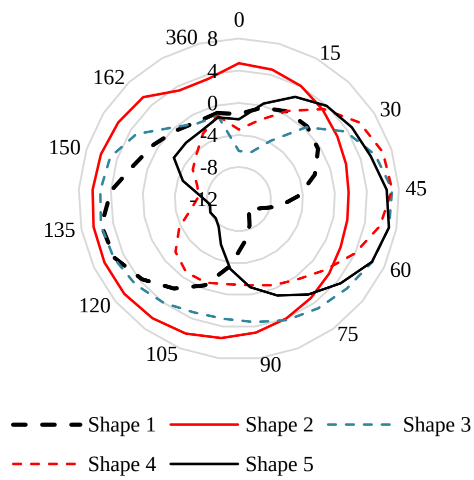


Fig. 9. Simulated 2D radiation pattern of reconfigurable antennas.

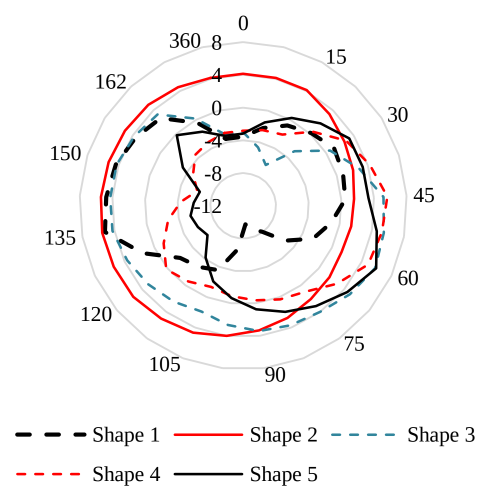


Fig. 10. Measured 2D radiation pattern of reconfigurable antennas.

Table 1: Performance comparison at different shapes

Shapes	Freq Range (GHz)	Bandwidth (GHz)	Simulated Gain (dB)	Measured Gain (dB)
Shape 1	2-4	2	5.2	4.31
Shape 2	4-6	2	6	5.53
Shape 3	8-10	2	7	5.83
Shape 4	10-12	2	5.1	5.23
Shape 5	6-8	2	6.8	5.93

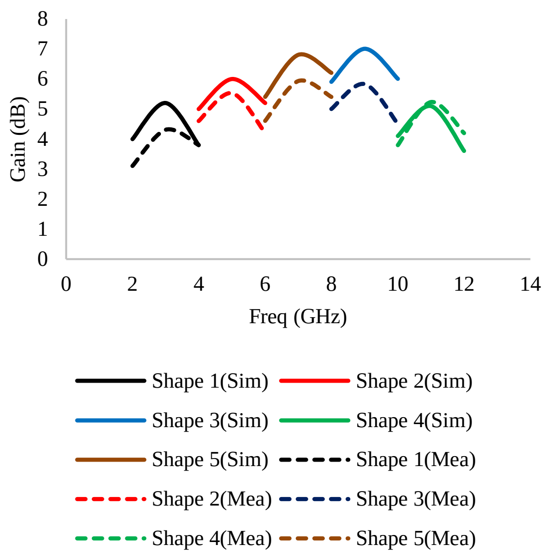


Fig. 11. Gain of the sensing antenna.

The simulated and measured efficiency with respect to the operating band is given in Fig. 12. It is observed that the antenna achieves nearly flat efficiency characteristics over the operating band with a maximum efficiency of 78%.

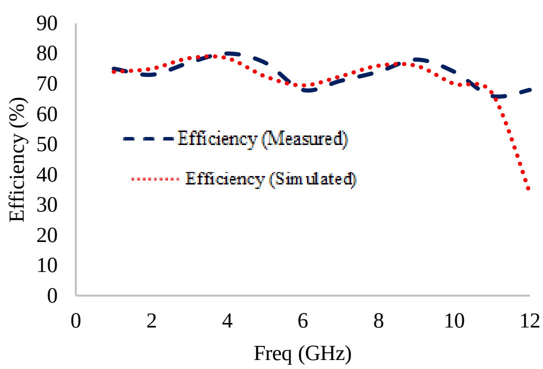


Fig. 12. Efficiency plot.

C. Radiation pattern of the reconfigurable antenna

The radiation pattern measurement is taken in the Anechoic Chamber at the Antenna Research Center (ARC), UiTM, Shah Alam, Malaysia, and the setup is shown in Fig. 13. The prototype is fabricated by rotating the shapes in the simulation. Each prototype has a U shaped wideband sensing antenna along with one reconfigurable antenna connected to the coplanar feed.

All the five reconfigurable shaped prototypes have been tested in the anechoic chamber and one such setup is presented below as an example. It can be noted that the shapes tries to radiate with minimal loss in gain. This is of vital importance to the considered design and its application in cognitive radios.

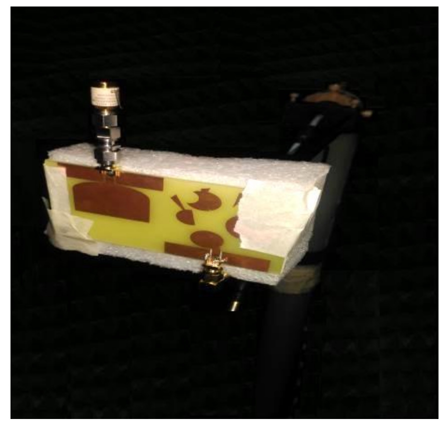


Fig. 13. Radiation pattern measurement setup at ARC, UiTM, Shah Alam, Malaysia.

D. Coupling between the two antenna modules

Since the sensing and the reconfigurable antennas are placed on the same substrate it is essential to avoid interference and minimize the coupling between them. The mutual coupling between the two ports would affect the transmission parameters and hence care has to be taken to keep the coupling at its minimum. As shown in Fig. 14, shows coupling isolation of 15dB was achieved with a peak coupling isolation of 40dB. The min/max coupling between the various shapes of the reconfigurable antenna and the sensing antenna is given in Table 2. The proposed antenna design is compared with other existing antenna designs and the performance comparison is tabulated in Table 3. The proposed antenna structure has a sensing antenna and tracking antenna on a single substrate having Omni-directional pattern for sensing antenna and directional pattern for reconfigurable antennas. The reconfigurable antennas are carefully spaced to avoid interference between one another and hence capable of tracking the white spaces.

E. Reconfigurability through rotation controlled using Arduino Microcontroller

In order to practically realize and to achieve the reconfigurability through the rotation, the prototype antenna is controlled directly using Arduino

Microcontroller which can be easily programmable as per the requirements. The reconfigurable antenna section is connected with the Servo Motor sg90 along with the Servo Motor Shield L293D and it is powered with 5v supply. The servo motor can be rotated to 180° clockwise as well as 180° anticlockwise. The trigger pin is used to control the rotation of servo motor ON/OFF state based on the given input angle. The antenna is mounted in an acrylic platform and the rotating part is mounted in the blades of the servo motor. The experimental setup of rotational reconfigurability is shown in Fig. 15. Initially, the position of the servo motor is in zero degree position. As per the design calculations of the antenna, angular position for the each antenna is known. The Microcontroller has been programmed to rotate in steps based on the angle of separation between the shapes. The antenna position is initially considered as origin angle that is zero degree. The servo motor is fed with the input angle of 37° for the following antenna in the clockwise direction. The servo motor stops the rotation when the feed and the antenna is in contact based on the input angle. After the second antenna it will rotate another 37° to cover the third antenna. After that it will rotate 99° to reach the fourth antenna in the clockwise direction. After that it will come to the initial position and rotate 127° in the anti-clockwise direction to reach the 5th antenna. The servo motor after moving for a certain angle corresponding to a particular reconfigurable antenna stops at a position where the feed and the antenna are in contact. The metal contact has been established between the feed and the reconfigurable shape. The duration of pause between the consecutive antennas is configurable as per the requirement of operation by modifying the delay parameter between each trigger. The time for which the antenna has to be in contact with the feed line is programmed by applying a delay to the servo motor. Since this rotatable antenna does not need any additional software and computer to control the rotational motion of the motor the switching between the antenna elements is faster and hence tracking is faster .The operation continues for the rest of the shapes and the result obtained through rotation is measured using Vector Network analyzer.

Table 2: Coupling isolation between the two modules

Shapes	Max (dB)	Min (dB)
Shape 1	27	15
Shape 2	28	16
Shape 3	35	17
Shape 4	31	15
Shape 5	40	15

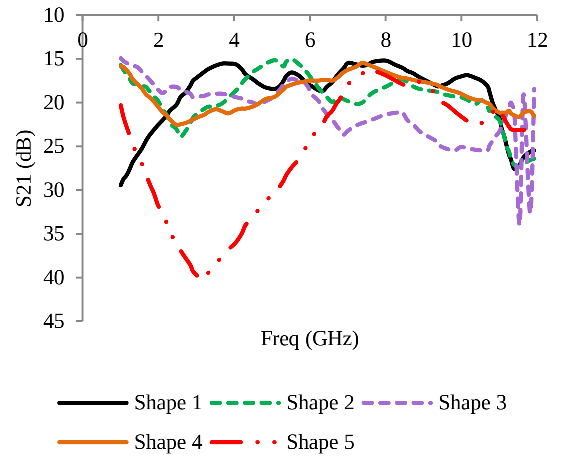


Fig. 14. Coupling isolation between the input ports (S_{21}).

Table 3: Comparison with existing designs

Ref.	Dimension (mm)	Operating Frequency (GHz)	Peak Gain (dB)
[1]	70× 50 × 1.6	2-10	8.45
[3]	50× 60 × 1.6	0.9-2.5	4.742
[4]	30× 30 × 1.6	4.7-5.03	2.73
[5]	50 × 50 × 1.6	2-7	5.9
Proposed work	100 × 60 ×1.6	2-12	5.83

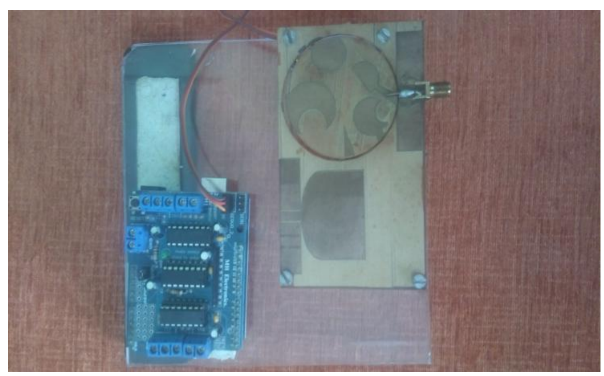


Fig. 15. Experimental setup of rotational reconfigurability using Arduino Microcontroller.

IV. CONCLUSIONS

This paper provides an insight towards designing a rotatable reconfigurable antenna and how it can be used as an RF transceiver for cognitive radio applications. As discussed above a UWB sensing antenna is designed which is operational from 2-12 GHz along with reconfigurable antennas serving the entire spectrum of

UWB. A significant coupling isolation of 15dB is achieved which provides sufficient isolation between the two ports enabling it to function together without performance degradation. Given the obtained results, the proposed structure holds good to serve as a transceiver for a CR system for sensing and tracking applications. In future by adding a GSM module the antenna can be controlled using mobile application.

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