5.8 GHz Retrodirective Array Phase Modulator

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Abstract : The paper focusses on implementing a 5.8 GHz Retrodirective Array Phase Modulator (RAPM) with ability to reradiate transmitted waveforms with QPSK modulation. For the implementation, the RF parts of circuits were simulated using ADS, the layout was done in Eagle and fabrication was done in the in-house fabrication facility by the students themselves. This is done as a part of Project 1 of ECE6361 Class Microwave Design Lab in Summer 2010 under Dr. Gregory Durgin.

I. Objective

The objective of this project is to produce a device capable of generating retrodirective array phase modulator (RAPM) in the 5.8 GHz ISM band capable of transmitting a random QPSK signal.

II. Introduction

Retrodirective array of antennas was developed first by L.C. Van Atta in 1955. As in [1] and [2], the retrodirective array has a unique property of reradiating back the waveforms to the source. Retrodirective array is an intelligent way of reradiating the waveforms without using costly equipments to steer the reradiating beam towards the source. In a retrodirective array, pair of antennas (say, two or four) are symmetrically arranged around the centroid of array. For example, say we have two antennas (A1 and A2) arranged symmetrically around centroid of array arrangement. So signal from source let first enter A2 antenna. Here the signal propogates down the antenna to the connecting transmission lines and crosses the centroid of array. When the signal crosses the centroid, the antenna A1 receives the signal and the signal from A1 propogates down the antenna to the centroid. Finally the signal that entered A2 comes out from A1 and the signal that entered A1 comes out from A2 and a uniform conjugate waveform of reflected waves is created.

During the process of reradiating the received waves, the length of the transmission line between the antennas can be changed in multiples of the wavelength to change the phase of the received signal and create a phase shift keying (PSK) modulation. The current project is aimed at generating QPSK modulation in RAPM for which 4 different lengths of transmission lines can be used to create modulated-reradiated waveforms with different phases. The transmission lines can be selected using a very low-power microcontroller.

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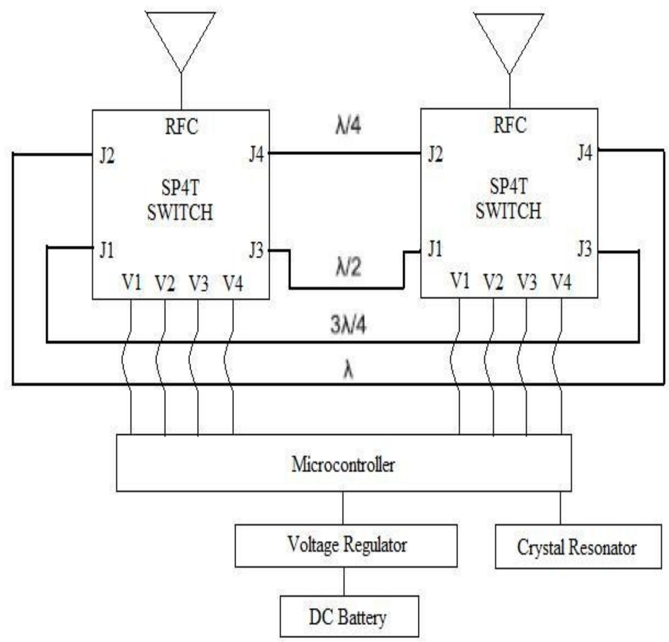
III. Design Specifications

- Operation within 5.725-5.850 GHz ISM band.
- Capable of reflecting a random sequence 100 kbaud QPSK signal.
- Two antenna elements must be detachable i.e. board and antenna must be SMA connectible.
- The board must be driven by a coil cell Lithium ion battery but must also have a breakout for external power supply.



IV. System Overview

The system is divided into two parts. The first part is the microcontroller circuitry part and the other is the switch part. The microcontroller part has a low-power microcontroller MSP430F2013, a 3V voltage regulator LT1461DHS8-3#PBF-ND, a crystal resonator FQ7050B, a 14-pin connector WM26914-ND and a battery holder BH600 to hold a 3V Lithium ion battery. The switch part consists of two four-pole switches SKY13322-375LF connected by different lengths of coplanar lines.

The two parts are fabricated on separate FR4 boards to make the Printed Circuit Boards (PCB) as shown in the Fig. 2 so that the output of microcontroller can be separately generated and tested and given to the switch part.

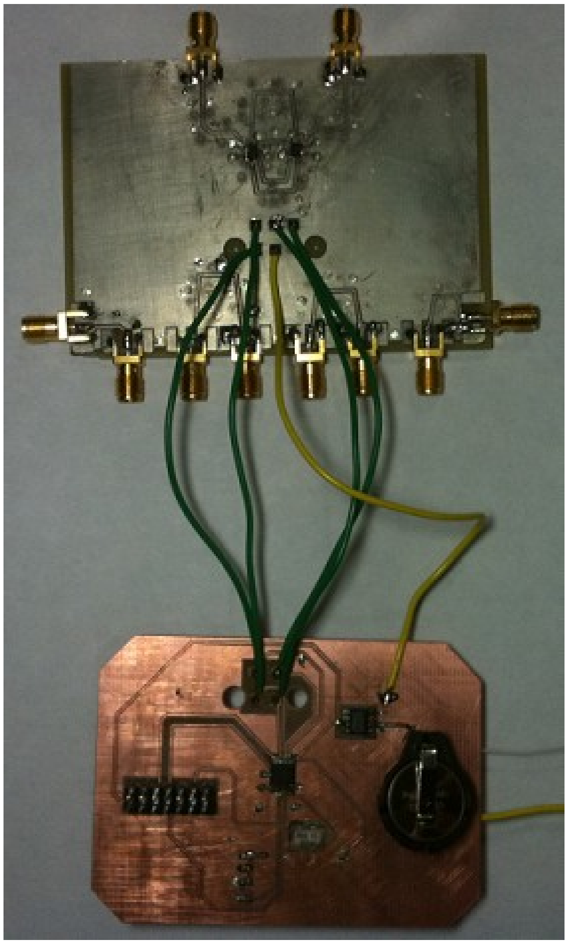


Fig. 2 Photograph of the developed RAPM system

V. Microcontroller Part

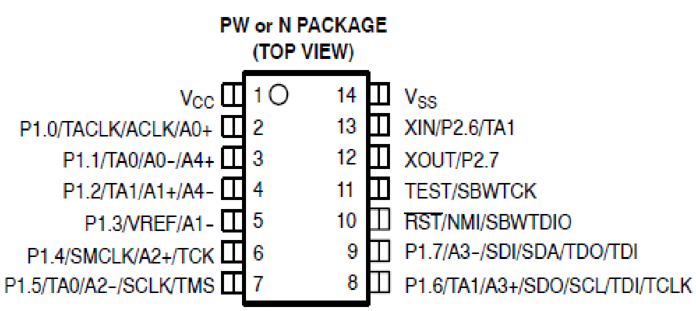


Fig. 3 Schematic Diagram of MSP430F2013 IC

The microcontroller MSP430F2013 program code was prepared in IAR Embedded Workbench IDE using C language. The code is included in the Appendix A. The code is designed such that only one of the pins P1.0, P1.1, P1.2 and P1.3 is high at one instant and the other three pins are low. To make this pin action possible, these pins are first defined as output pins in the code, interrupt is enabled and the microcontroller is sent to sleep mode. On receiving interrupt, the microcontroller becomes active again from sleep mode. The microcontroller is given interrupt such that the baud rate of switching of pins is 100 kbaud. To achieve this baud rate the CCR0 of the timer is set to 50 and substituted in equation(I), which is equation for the baud-rate generation of the microcontroller. Substituting the value of oscillator clock of 10MHz obtained using crystal resonator in to the equation (I) gives 100 kbaud of baud rate.

$$\text{Baud-Rate} = \frac{\text{Oscillator Clock}}{\text{CCR0*2}} \tag{I}$$

The microcontroller interrupt is selected in such a way that only one pin out of four become active high randomly. To achieve this, random integers from 0 to 3 are generated and switch case of C code is used to select one out of the four pins and make it high.

The pins P1.0 to P1.3 are connected to four different vias and wires are attached to them and the other end of wires is connected to the four different vias on the switch part PCB.

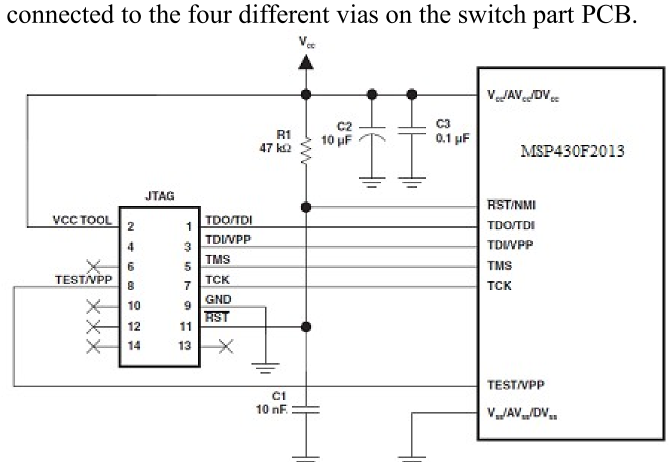


Fig. 4 Signal Connections for 4-Wire JTAG Communication

To program the mircontroller, a 14 pin JTAG connector is added on PCB and is connected to microcontroller as shown in Fig. 3 in the 4-wire JTAG communication mode. The capacitors and resistors used were SMD components of size 0603.

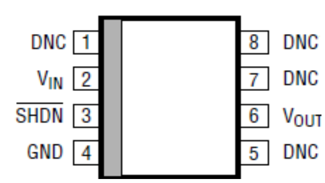


Fig. 5 Schematic Diagram of Voltage Regulator IC

The microcontroller needs 3V supply for its steady operation. To achieve this target, the voltage regulator LT1461DHS8-3#PBF-ND is used. The input from 3.3V coil cell Lithium ion battry is given to Vin pin of the voltage regulator and steady 3V is obtained from output of the voltage regulator.

The schematic and layout of the microcontroller part is done in Eagle (Version 5.9.0, Light Edition) which are shown in Appendix B.

The PCB is fabricated in the in-house PCB fabrication facility in Georgia Tech ECE department. Gerber files are generated from the layout files and imported into the IsoPro software on PCB fabrication machine. The drill sizes were manually changed for different via sizes. After fabrication, the PCB is tinned to improve the solder-adhesion over the PCB.

VI. Switch Part

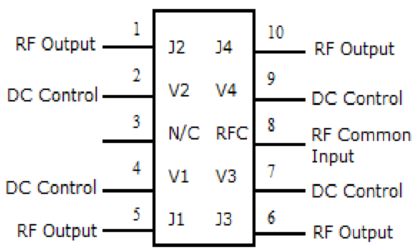


Fig. 6 Schematic of Four-pole Switch SKY13322-375LF

The two four-pole switches SKY13322-375LF are connected to each other by the different lenghts (λ/4, λ/2, 3λ/4, λ) of four different coplanar lines. The schematic and layout of switch part PCB done in Eagle (Version 5.9.0, Light Edition) are shown in Appendix C. To create the coplanar lines between the switch to generate the RAPM, LineCalc tool of ADS is used.

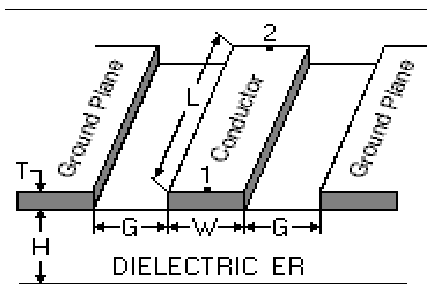


Fig. 7 Schematic of a Coplanar Line to show L, W and G

The following general parameters are entered in LineCalc :

- FR4 Board thickness = 31 mil
- Permittivity of FR4 = 4.47
- Conductivity of FR4 = 5.8108e7
- Loss tangent of FR4 = 0.016
- Copper thickness = 1.4 mil

The frequency is selected as 5.8 GHz and characteristic impedance is selected as 50Ω since the characteristic impedance of the switch RF pins is 50Ω. Finally different values of phase are entered i.e. 90, 180, 270 and 360 and following values of W, G and L are obtained where W is the width of coplanar line, L is the length of coplanar line and G is distance between conducting line and ground plane in coplanar line.

- For 90 degree phase shift : W=21.924685 mil, G=5.00 mil, L= 318.024016 mil
- For 180 degree phase shift : W=21.924685 mil, G=5.00 mil, L= 636.047244 mil
- For 270 degree phase shift : W=21.924685 mil, G=5.00 mil, L= 954.070866 mil
- For 360 degree phase shift : W=21.924685 mil, G=5.00 mil, L= 1272.094488 mil

So to achieve different phases, length of the coplanar line is changed and width and distance of conductor from ground are kept constant.

VII. Critical Analysis of Results

a. Switch Part

Table 1

Measured S21 Phase Change, Re(Z_0), Im(Z_0) at 5.8 GHz

	S21 Phase Change (Degree)	**Re(Z_0) (Ω)**	**Im(Z_0) (Ω)**
3λ/4	-173	23.45	-2.34
λ/2	-43.5	62.96	-24.18
λ/4	4.68	63.96	1.37
λ	135	13	19

Coplanar lines other than those between 4-pole switches were fabricated on the PCB, SMA connectors were connected to them and the S21 phase change, Re(Z_0) and Im(Z_0) were measured at 5.8 GHz.

Here the phase difference does not increase as you observe the lengths increasing from λ/4 to λ but the the phase variation is such that the value of phase goes from -173 degree to 135 degree with sequence 3λ/4, λ/2, λ/4 and λ. These phase values were obtained because while making the layout for these additional coplanar lines, ground vias were not kept in some of the closely spaced areas near SMA connectors and as a result the expected coplanar line was not fabricated and no ground was obtained surrounding some parts of coplanar lines.

Also, eventhough the ADS calculated values of line lengths were used in layout, the characteristic impedance of lines was not 50Ω but was different. Particularly the characteristic impedance of λ-length and 3λ/4-length lines was much lower. This also occurred due to absence of thin vias near closely spacecd SMA connectors. But this should not affect the phase change. However the mismatch between the coplanar lines and the switch pins would lower the backscattered power efficiency.

Also, while making the layout for switch part, considering the difficulty of passing the RF signal pin of the 4-pole switch, the RF signal pin was passed from bottom of chip taking into consideration the datasheet. But during actual mounting of parts, it was realized that there is a ground below the 4-pole switch. So in the switch part PCB, the RF signal pin got grounded when the switch was mounted.

The solution to this was thought to be applying white insulating paste below the switch but the solution could not eleminate the problem since the white insulating paste was not in good state while fabrication. Also the other solution thought was to create a via near RF pin, send the RF signal from switch to SMA connector from bottom ground plane and razor-blade etch the RF signal from switch bottom. But this would add very high inductance at 5.8GHz and so this idea could not assist.

b. Microcontroller Part

The microcontroller PCB was fabricated using the 4-wire JTAG communication for programming the microcontroller. But success was not obtained in programming the microcontroller MSP430F2013 in 4-wire JTAG communication mode. However, it was observed that other group obtained success in programming the microcontroller using 2-wire JTAG communication mode.

VIII. Precautions

Following are precautions that can be taken for future similar projects :

- Check the actual components before making the layout since in our case the 4-pole switch has ground at bottom and we passed RF signal from switch bottom.
- While soldering tiny components like microcontroller IC, use solder-paste and oven heating instead of hand soldering since hand soldering increases difficulty of soldering and increases probability of shorts.
- While using hot gun to remove critical soldered components like soldered ICs, keep the temperature around 250 ºC and not more since increasing the temperature would burn the IC.
- After using oven heat or hot gun to remove components, lift the components gently, otherwise the pads would come off the PCB (especially when the PCB is in-house manufactured) since our microcontroller pads came off due to same reason which led us to fabricating a new board.
- Put small vias around closely spaced places (particularly around coplanar lines) as their absence would not give you coplanar lines after PCB fabrication.

IX. Conclusion

Thus, by implementing the project of 5.8GHz RAPM generation, we learned different phases of PCB-making namely real-world microwave circuit design, PCB layout, actual fabrication of FR4-based PCB board and tinning of the PCB.

References

[1] G.A. Koo, Y. A. Lu, G.D. Durgin, “Retrodirective Array Phase Modulation for Ultra Low-Power Communications”, IEEE Antennas and Wireless Propogation Letters, 2010.

[2] L. C. Van Atta, “Electromagnetic reflector,” US Patent 2,908,002, October, 1959.

[3] J. D. Griffin and G. D. Durgin, “Complete link budgets for backscatterradio and rfid systems,” IEEE Antennas and Propgation Magazine, vol. 51, pp. 11–25, April 2009.

[4] Eagle training: http://vulcan.ece.ucsb.edu/ece189-2007-08/tutorials.html

[5] T-line parameters: http://emclab.mst.edu/documents/TR00-1-041.pdf

Appendix A : Microcontroller Code

```
#include <msp430x20x3.h>
#include <stdio.h>

unsigned int setState(unsigned int);
static unsigned int randnum[16] = {3, 2, 0, 3, 1, 3, 0, 2, 1, 3, 0, 1, 2, 3, 1, 2};
static volatile unsigned int index = 0;

void main(void)
{
  // Stop watchdog timer to prevent time out reset
  WDTCTL = WDTPW + WDTHOLD;
  // Set P1.0 to P1.3 as output
  P1DIR |= 0x0F;
  // CCR0 interrupt enabled
  CCTL0 = CCIE;
  CCR0 = 50;
  // Auxilary CLK, continuous mode
  TACTL = TASSEL_1 + MC_2;
  // Low power mode, global interrupt enable
  _BIS_SR(LPM0_bits + GIE);
}

#pragma vector=TIMERA0_VECTOR
__interrupt void Timer_A(void)
{
  setState(randnum[index]); // Assign values to P1.0 - P1.3
  index++;
  // Index resets at 16
  if (index == 16)
    index = 0;
  CCR0 += 50;
}

unsigned int setState(unsigned int state)
{
  switch (state)
  {
    case 0:
      P1OUT |= 0x01;
      break;
    case 1:
      P1OUT |= 0x02;
      break;
    case 2:
      P1OUT |= 0x04;
      break;
    case 3:
      P1OUT |= 0x08;
      break;
    default:
      P1OUT |= 0x00;
      break;
  }
  return 0;
}
```

Appendix B : Schematic and Layout of Microcontroller Part of PCB

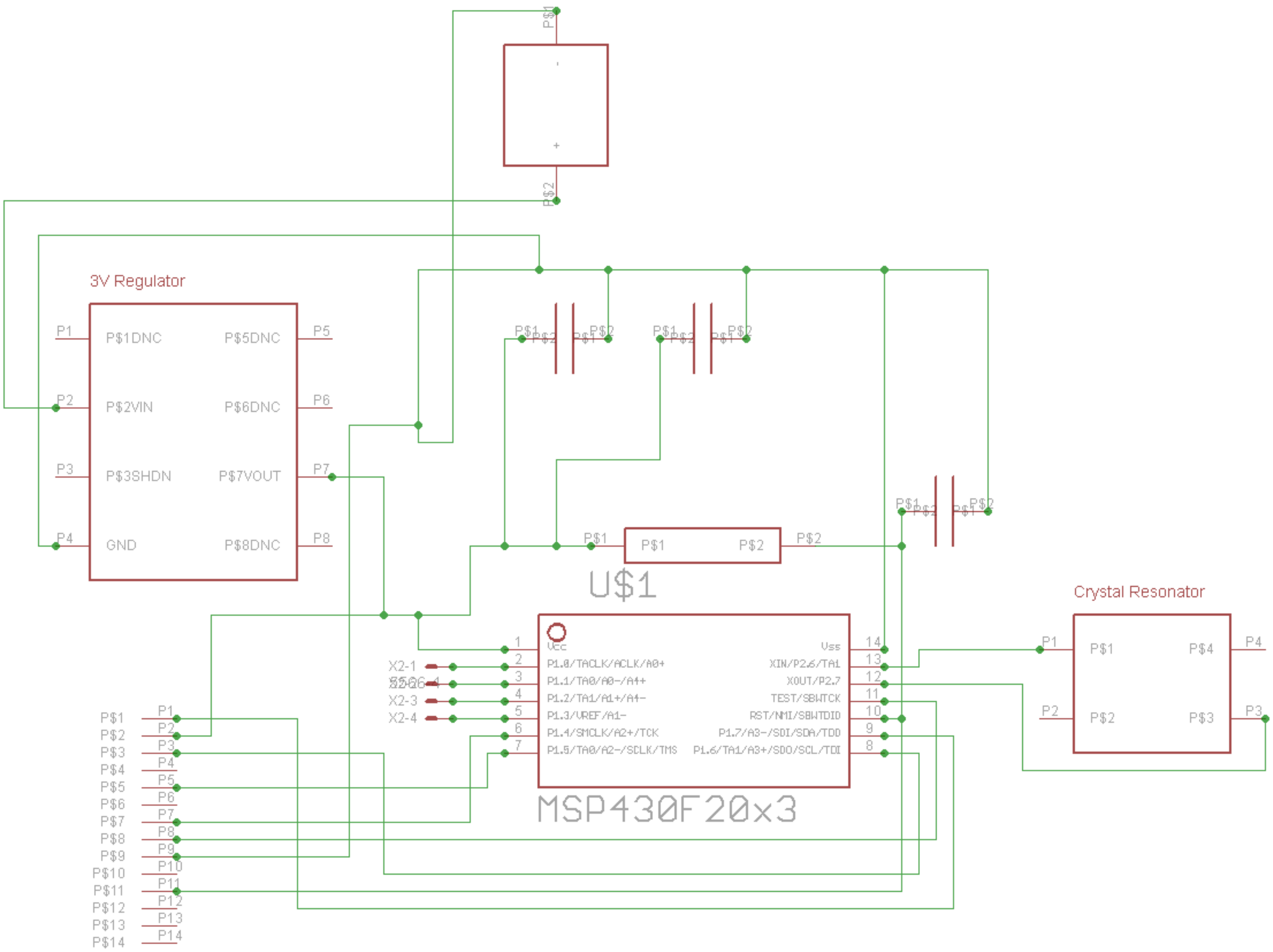


Fig 1. Schematic of Microcontroller Part of PCB

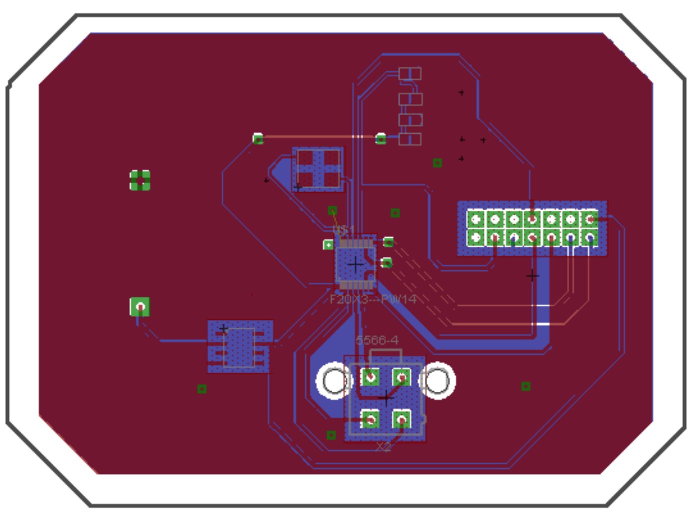


Fig 2. Eagle Layout of Microcontroller Part of PCB

Appendix C : Schematic and Layout of Switch Part of PCB

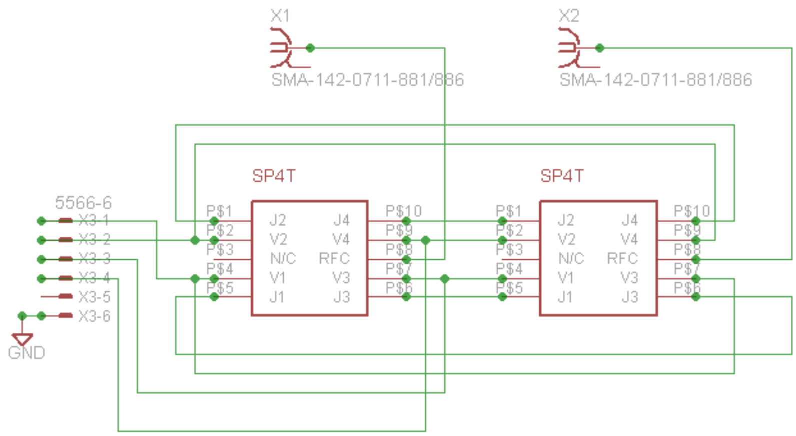


Fig 1. Schematic of Switch Part of PCB

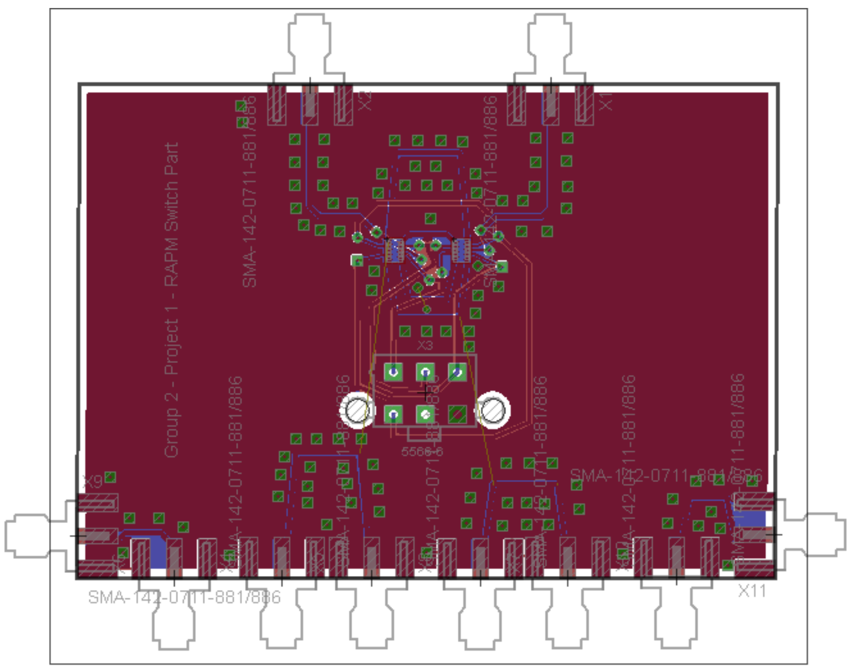


Fig 2. Eagle Layout of Switch Part of PCB