5.8GHz Retrodirective Array Phase Modulator Backscatter System

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Abstract— **This paper describes the design and implementation of a phase array modulator capable of generating and transmitting a QPSK signal. The device uses the phase shifting properties of transmission lines as well as the reflection properties of a retrodirective array. The advantage of this system is that wireless communication can be achieved without the need for additional hardware such as phase shifters, local oscillators, or mixers. For this device, a 2 element array will be considered.**

Index Terms—**Retrodirective array, Backscatter modulation, Phase modulator**

I. Introduction

THE retrodirective array (RA) developed in 1955 by L.C. Van Atta has a very unique property in that any incident wave is reflected back toward the source. One can take advantage of this property in order to transmit useful data by modulating the incident wave before it is reflected. Phase modulation can be implemented by selectively altering the phase of the incoming signal at specified intervals. This can be accomplished by using low-loss transmission lines of a certain length. Quarter-wave transformers exhibit a 90 degree phase shift between the input and output, and are a simple way of implementing a QPSK modulator.

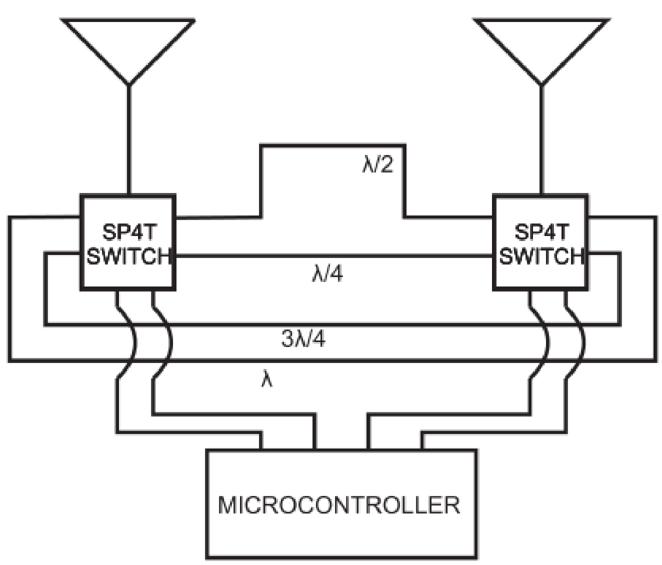

Fig. 1. Two element RA phase modulator

By using four transmission lines, each a quarter-wavelength longer than the previous, one can generate a full QPSK sequence. The microcontroller can then be programmed in order to transmit any set of data back to the source.

II. Design Methodology

In this project, we design the RAMP board with three separate PCB boards because of the convenience of design and testing. By doing so, the RF ground and digital ground automatically are separated and the antennas can be easily measured and matched. The RAMP board is designed to be able to use both battery and power sources. To connect to the JTAG programming interface, we printed a 14-pin header into RAMP board. The clock of microcontroller was fed from the external crystal oscillator. However, due to ambiguous pin configuration of crystal oscillator in datasheet, the external crystal oscillator did not work. Instead, we use the internal clock to generate square wave. To meet the specification of 100kbaud, we set up the clock frequency of 100Khz. For applying precise and accurate low power to microcontroller, the supply of microcontroller is connected to voltage regulator (LT1461). The power supply required to operate the circuit is about 3.3 V. The voltage regulator regulates the input of the microcontroller to 3V. Since our design targets normal temperature condition, the shutdown mode is turned off. The micro controller chip is programmed by USB-connected JTEG which is provided by TI. As we expected, the internal clock is too noisy to play with RF switch accurately. Thus, to reduce the effect of the undesired noisy clock on the overall system, small dead gap between switching is added.

A. RF Section

In order to simulate the QPSK modulation of the signals received through the antenna, first the wavelength of the transmission line was calculated using the equation below,

$$\lambda = \frac{c}{\sqrt{\varepsilon_r} \cdot f} = 24.37mm$$

with ε_r=4.5 as the dielectric constant of FR4.

For accurate simulations using coplanar waveguides, the gaps and width of the transmission lines were calculated using ADS Linecalc and simulated as shown in the figures below.

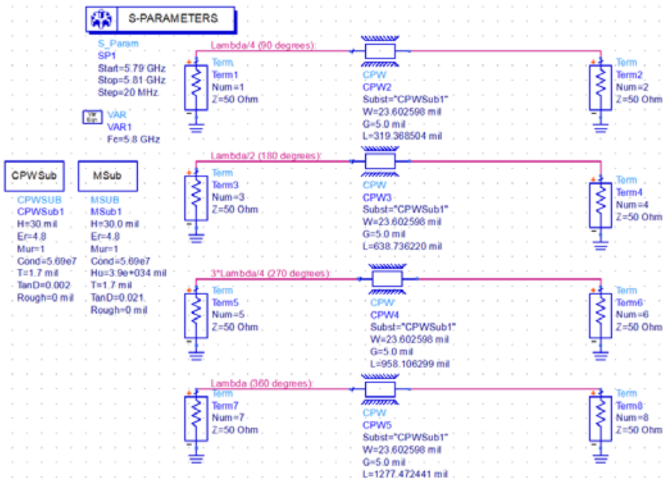

Fig. 2. ADS Simulation schematic

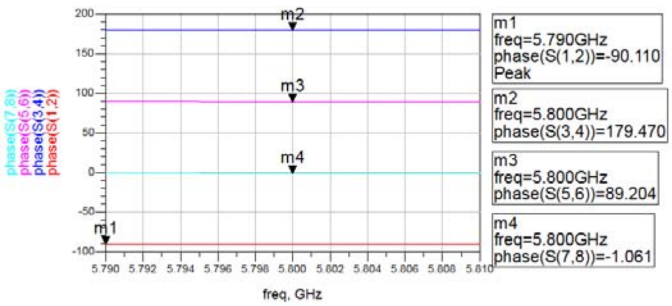

Fig. 3. ADS Simulation result

Figures 2 and 3 show that there is almost 90 degrees phase shift between each of the traces that are quarter wave length apart. The dimensions of the transmission lines required to get the required phase shift are summarized in the Table 1.

Table 1. Transmission line dimensions

Transmission Line	length (mm)	Phase Shift (degrees)
M1	6.092	-90
M2	12.183	180
M3	18.275	90
M4	24.366	0

In order to connect the transmission lines, RF switches are used. Figure 4 shows the schematic used to connect the switches to the corresponding control lines and RF traces.

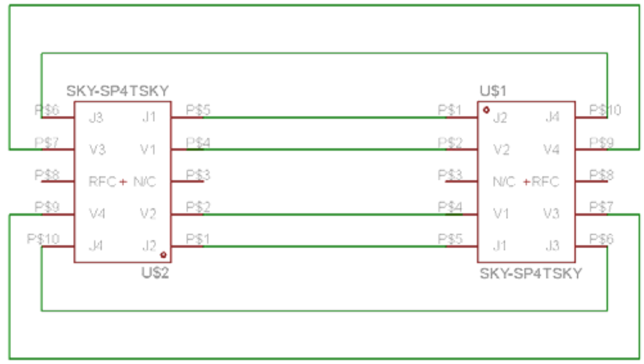

Fig. 4. Switch schematic with control (inside) and transmission lines (outside)

For the layout, Eagle software was used to layout the simulated transmission lines and switches. In particular, the corners of the transmission lines were made 45 degree angles rather than 90 degrees to avoid discontinuities that can cause random phase shifts and signal attenuation. Also, the transmission lines were made using coplanar waveguides rather than microstrip lines to minimize coupling effects and to reduce the line widths. The layouts are shown in the Appendix.

B. *Digital Section*

As you can see at Figure 5, the digital part of the RAPM circuit consist of 14-pin header, a voltage regulator, a crystal oscillator, and TI MSP430 microcontroller.

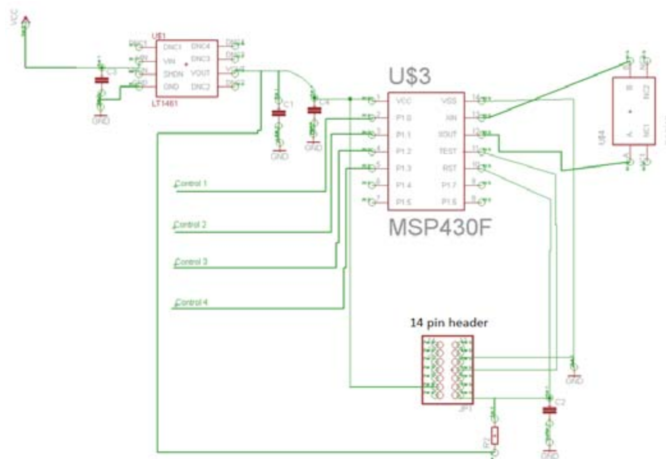

Fig. 5. Schematic of Digital section

We used the software called IAR Embedded Workbench IDE to program the microcontroller. The development enviornment can be setup using the following settings.

-Target device: MSP430F3013
- Language: C
- C dialect: C99
- Debugger: FET Debugger (Not simulator)
- Connection: Texas Instrument USB-IF/ Automatic

To complete mapping the code into microcontroller, we used the command of download and debug. Since this command is for debugging, we had to fully debug the code up to the end of code first.

III. Fabrication

The RF and digital sections were fabricated on separate boards for the convenience. The substrate was 30mil FR4 with 1.4mil copper. The finalized boards are shown at the Figures 6 and 7.

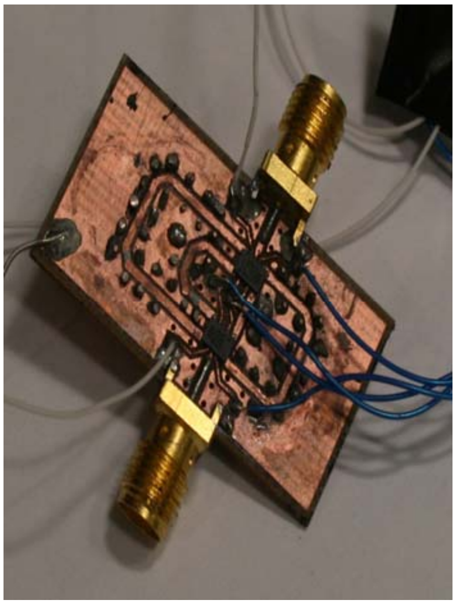

Fig. 6. Fabricated RF section of RAPM circuit

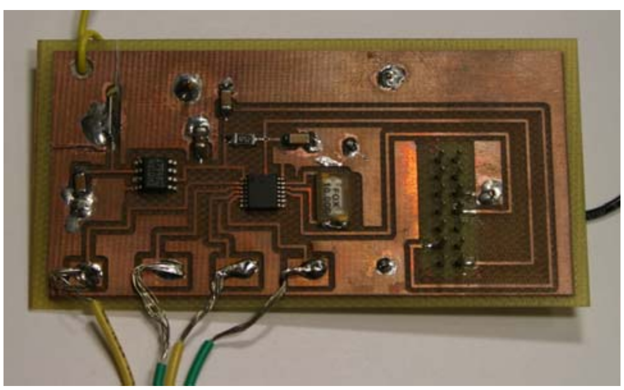

Fig. 7. Fabricated microcontroller section

IV. Results

The RAPM device was tested by connecting to a network analyzer. The network analyzer was used as a signal generator to produce a continuous 5.8GHz tone. The microcontroller was programmed to output a QPSK sequence. By measuring the S_{21} and displaying the data on a real and imaginary axis, the QPSK constellation can be measured, as shown in the figure below.

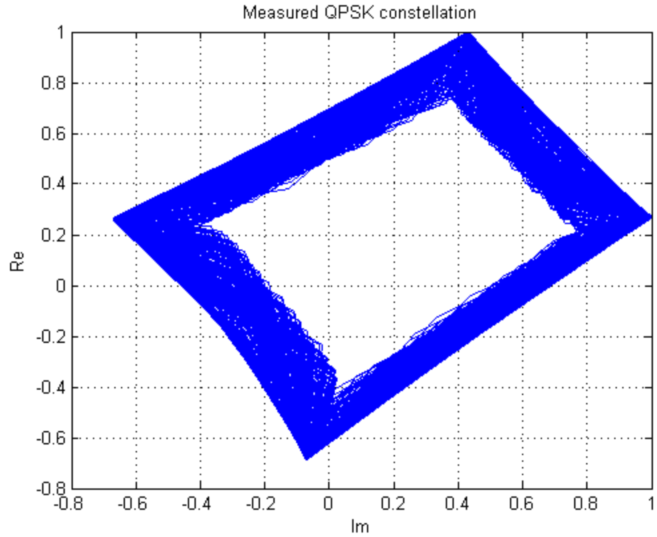

Fig. 8. Measured QPSK constellation (normalized)

The measured constellation shows four distinct points that are approximately 90 degrees apart. However, there are several reasons for the discrepancies. The internal clock of the microcontroller is noisy and unstable, causing the oscillation frequency of consecutive bits to be slightly different. Another reason could be the effect of coupling in different RF channels and noisy output of micro-controller. Inserting via in the board eliminated the coupling problems a little, but it could not improve the quality of QPSK modulation significantly. To improve the eye diagram, multi-layer board can help to decouple the noise and remove long jumper wire which is used to connect to digital boards. This is because we observed that the shape of constellation was changing when we tilted the board and moved the wires. In addition, the insertion loss input and output terminals was approximately 13dB. This is partially due to the difficulty in placing enough vias next to the transmission lines to prevent the electric fields electric fields from leaking into adjacent traces.

V. Conclusion

The demonstration of a clean QPSK modulation pattern produced by the RAPM module demonstrated the success of the RAPM theory and design. However, the fabrication methods used were not capable of producing a consistent, reliable module.

References

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