Design of an Open-Source Modular RF Switch Matrix for Microwave Imaging

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***Abstract*—Measurements from multiple antennas provides diversity in the data for imaging. To take measurements from many antennas using an instrument with only a few ports, one needs to switch connections by hand or use a switching instrument. Switching instruments are available but are typically expensive, this project will introduce an alternative low-cost electronic switching device. We present an RF switch matrix PCB, designed for low insertion loss across 0.1 – 6GHz using controlled impedance traces, that is modular such that multiple boards can be connected to increase the total number of switching ports.**

***Index Terms*—Microwave Imaging, RF switch matrix**

I. Introduction

MEASUREMENTS of RF signals in the microwave frequency range are found to be helpful in imaging breast tissues for tumor detection [1]. Microwave frequencies are non-ionizing in nature compared to X-Ray making them suitable for non-invasive imaging of human tissues. Typical RF measurement devices, like Vector Network Analyzers (VNAs), have base models consisting of 2 ports and typically cost upwards of $10000. RF measurement devices with many ports exist but are much more expensive than the base model. RF switching instruments, which switch the VNA measurement ports with a collection of additional ports, are available but are typically expensive, so an alternative low-cost device is desired. In this project we present the initial design of an RF switch matrix, fabricated on a Printed Circuit Board (PCB) with controlled impedance traces, designed for low insertion loss across a wide frequency band of 0.1 – 6GHz.

II. Design

This section will summarize the design of the RF switch matrix, including the PCB design and the control design. Our initial design is a 4 by 2 switch matrix, however the same design concepts can be mimicked to design larger systems (8 by 2, 16 by 2, etc.). The goals of our design are sufficiently low reflection (return loss > 10dB) and low attenuation of our signal (insertion loss ≈ 1dB at 1GHz and ≈ 2dB at 6GHz).

A. Overview

A top level diagram of the 4 by 2 switch matrix is shown in figure 1. The VNA's RF ports are connected to TX and RX on the switching matrix via an SMA cable, although directionality of these ports are shown this is only for conceptual convenience. The VNA connects to a microcontroller ('μC') through a serial interface, which is then responsible for controlling the switches on the board. External antennas to be switched are connected to the PCB through SMA cables. An external power supply provides $3.3\,\mathrm{V}$ to the system.

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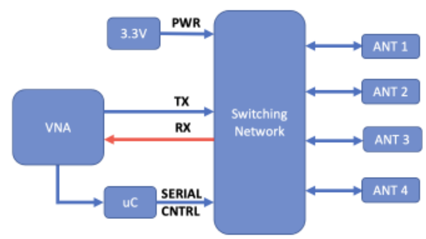

Fig. 1. Top level block diagram of a 4-antenna system.

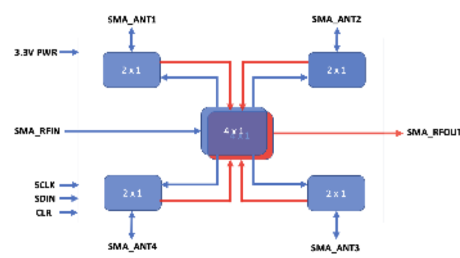

Fig. 2. Implementation of the 4-antenna switch matrix. 'SMA_RFIN' and 'SMA_RFOUT' are connections to the VNA.

B. PCB Design

The implementation of a 4 by 2 switch matrix is shown in figure 2, which is a high-level sketch of the fabricated PCB layout shown in figure 3. The PCB consists of 2 outer copper layers and 4 inner copper layers, all are a standard 1oz thickness, with uniformly thick ($0.203\,\mathrm{mm}$) Roger's RO4003C dielectric core between them. The RF traces were implemented using a grounded coplanar waveguide with $0.4318\,\mathrm{mm}$ trace width and $0.5\,\mathrm{mm}$ separation between trace and ground plane. Vias were stitched along the RF traces' exteriors for better shielding and containment of each signal. The design uses two kinds of switches: four 2 by 1 switches (Skyworks SKY13587-378LF) configure each antenna port to be connected to either the TX switch or RX switch, and two 4 by 1 switches (Skyworks SKY13575-639LF) control which antenna the TX and RX ports connect to. Each switch is connected to a central serial shift register, written to by the microcontroller, that provides their control signals.

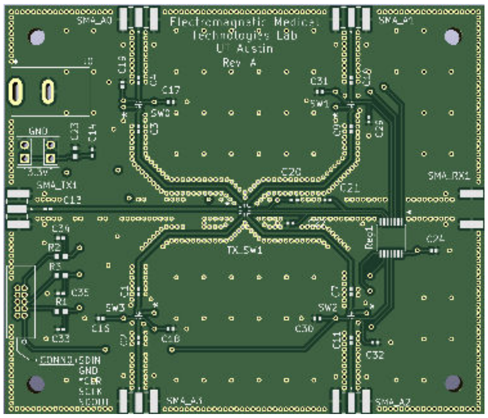

Fig. 3. Designed PCB for 4-antenna switch matrix. This is a 3D model of the fabricated PCB, not an image of the PCB received from the fabricator. Only the top layer is shown

C. Control Design

The VNA, or an external computer, issues commands via UART protocol to the microcontroller which then writes to the serial shift register that controls the switches on the board. The microcontroller used was Texas Instruments TM4C123 Tiva Launchpad, which was programmed using C. The control software for the VNA provided a simple user interface through the command line to operate the switch matrix.

III. Conclusion

While the initial proof-of-concept prototype was a success, another design iteration is required before this work could be made open source and available for anyone to fabricate and assemble themselves. Although a sufficient impedance match was made with an adequate level of return loss, the insertion loss did not meet our design standards. In the redesign, care must be taken to optimize the trace turns and routing which was likely the cause of the added attenuation.

IV. Acknowledgements and Future Plans

Spencer would like to thank IEEE's MTT-S Undergraduate Scholarship program for supporting this work, which has allowed him to solidify his microwave engineering knowledge. The funding helped with PCB fabrication cost, the components, and cables for testing. Spencer will be continuing his work with devices as he pursues a PhD in Biomedical Engineering at The University of Texas at Austin.

References

[1] A. Santorelli, E. Porter, E. Kang, T. Piske, M. Popovic, and J. D. Schwartz, "A time- domain microwave system for breast cancer detection using a flexible circuit board," *IEEE Transactions on Instrumentation and Measurement*, vol. 64, no. 11, pp. 2986– 2994, 2015.