

Microstrip Antenna System for Arbitrary Polarization Reconfigurability

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Abstract—A microstrip antenna system is presented that allows polarization to be changed dynamically. The patch is fed by two perpendicular microstrip lines whose magnitudes and phases are adjustable via a network consisting of a PIN diode switch, a variable power divider and two variable phase shifters. The system is designed for operation at 2.44 GHz and verified by simulations in HFSS and Designer. Measurements taken of a prototype confirm arbitrary polarization reconfigurability in principle with isolations of 3.9 dB and 8.8 dB between individual polarization states.

Index Terms—microstrip antenna, polarization, diode switch, variable power divider, variable phase shifter, reconfigurability.

I. INTRODUCTION

Antenna reconfigurability has been a topic of particular interest over the past decade. More flexibility in antenna designs not only makes it possible to reduce undesirable losses in wireless communication links, but can provide more sophisticated systems which adapt to their environments and user scenarios.

Wireless links are subject to many sources of fading, which contribute to low signal to noise ratios, low data rates or even complete loss of signal. One type of fading arises from antenna polarization mismatches. The polarization of an antenna is directly related to its geometry and orientation. These physical aspects are generally difficult to change dynamically, but through the use of a generic patch antenna with multiple feed points, it is possible to electrically adapt its polarization performance.

Past work devoted to polarization reconfigurability mostly targets switching an antenna between predefined polarization stages. Demonstrated antennas include switching between right-handed and left-handed polarization [1], and between linear and circular polarization [2]. Other antennas are able to be reconfigured to a more diverse set of polarizations [3], [4]. The antennas thus far, however, have been unable to reconfigure to any arbitrary polarization.

Therefore, this paper focuses on a patch antenna system that is capable of dynamically changing its polarization to any configuration. The device is divided into several portions for a modular design. The input port is first connected to a variable power divider which splits the signal into two with a variable ratio. The second component applies an adjustable phase shift to each signal to be fed into the square patch antenna. Finally, the patch antenna, with associated impedance matching,

radiates the resulting signals. The design is implemented for the 2.44 GHz ISM band and constructed using a Rogers RO4003C LoPro 32.7 mil substrate.

II. DESIGN

The feed network and antenna architecture are illustrated in Fig. 1. The square patch antenna is designed for 2.44 GHz and includes quarter-wavelength transformers to match the high edge impedance of the patch. Design guidelines are presented, e.g., in [5].

The feed network serves the purpose of changing the magnitude and phase of the voltage entering the patch antenna. It is comprised of a variable power divider and then variable phase shifters. The variable power divider splits, by any ratio, the input power into two. The variable phase shifters shift the channels relative to each other. Two phase shifters are used, one in each branch, to relax the requirement from a 0 to 360 degree phase shifter to only a 0 to 180 degree phase shifter.

Fig. 2 shows the board level layout of the design with its components labeled. The basic modules are explained below.

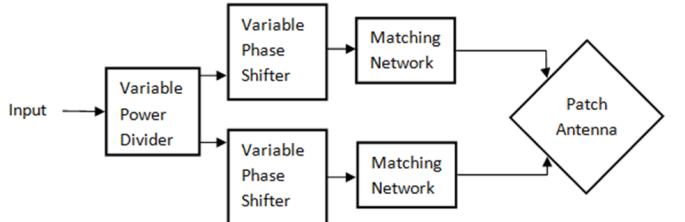


Fig. 1. Feed network and antenna architecture.

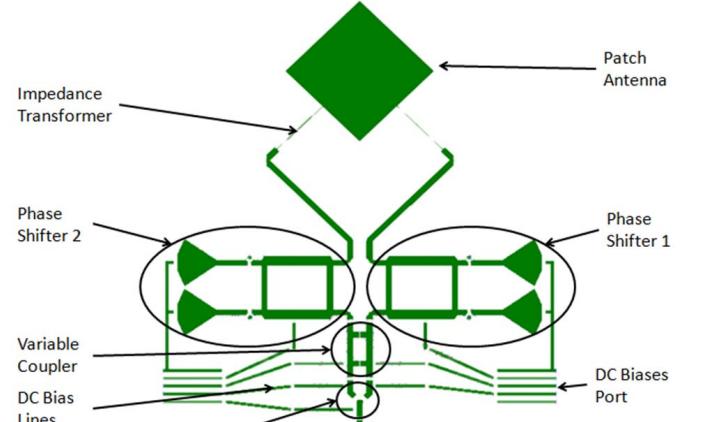


Fig. 2. Board level layout of microstrip antenna system for arbitrarily reconfigurable polarization.

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A. PIN Diode Switch

The first component following the input port is a SMP1340-079LF PIN diode switch to route the signal to one of the two inputs of the following variable coupler. The switch is modeled in Designer with the PIN diode on-state replaced by a through connection and the PIN diode off-state replaced by a gap. Insertion loss of about 0.07 dB is predicted, but this loss is expected to increase if a proper PIN model is used.

B. Variable Coupler

A variable coupler, slightly modified from [6], is employed as the variable power divider as shown in Fig. 1. It uses two varactor diodes in parallel, spaced 1/8 wavelength apart. By varying the capacitance of the varactor diodes, the power can be split continuously from full power to the through port to equal power output to the through and coupled ports. To allow full power to be delivered to one of the two output ports, the PIN diode switch as described above is used. Of course, the output ports of the variable coupler are 90 degrees out of phase. This must be compensated for when configuring the phase shifters.

For the diodes to connect both traces, the traces would require to be very close together, causing coupling. Such coupling would lower isolation between the output ports. To widen the spacing, branches are added between the traces with an appropriate gap to solder the varactor diodes.

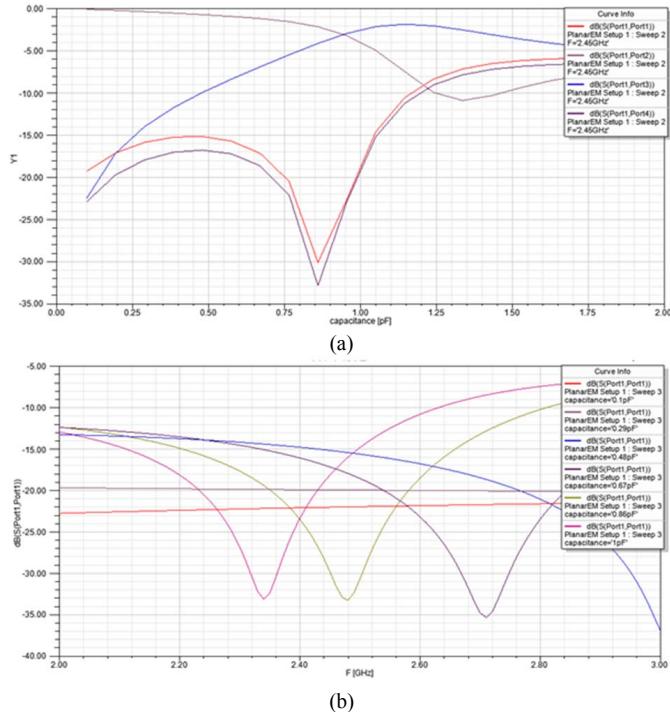


Fig. 3. Scattering parameters of the variable coupler versus capacitance (a), and reflection coefficient in dB versus frequency for different power settings (b).

Fig. 3a shows the coupler scattering parameters as a function of capacitance. The coupling between the output ports varies, as expected, from equal power output at 0.9 pF to greater than 15 dB isolation between the two ports. Capacitances beyond 1 pF are meaningless for this device as

the input impedance matching degrades rapidly. Within this realm of reasonable operation, the best impedance matching occurs at around 0.4 pF but loss remains below a reasonable -15 dB. Varactor diodes SMV2201-040LF were chosen, and the main criterion for their selection was their low capacitance at high bias potentials for best isolation performance between output ports.

Fig. 3b demonstrates that the reflection coefficient varies with frequency but that the changes are not significant, i.e. the coupler is not too narrowband, which makes performance only moderately dependent on the final manufactured device dimensions. Fig. 4 shows the assembled PIN diode switch and the variable coupler with biasing circuitry.

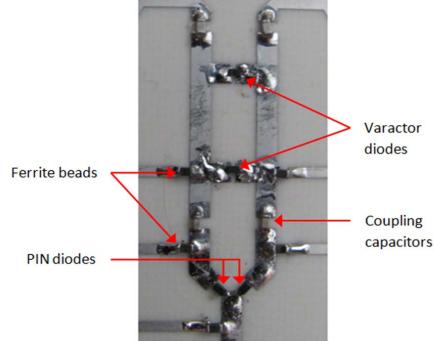


Fig. 4. Assembled PIN diode switch and variable coupler.

C. Phase Shifters

The phase shifters play a prominent role to allow arbitrary polarizations. The most stringent requirement for this device is the ability to shift the phase from 0 to 180 degrees.

The design of this component employs a 90 degree hybrid coupler with two identical capacitive loads on two arms. Hence the phase change caused by the capacitances of the terminated ports contributes to the transmission phase between the two remaining ports, e.g., [7]. The capacitive loads are composed of a transmission line in series with a varactor diode and inductor combination in parallel. Fig. 5 shows the final model in Designer including equivalent circuits for the SMV2201-040LF varactor diodes and an additional decoupling capacitor in series with the inductor to avoid shorting the DC bias of the varactors, and low-impedance stubs.

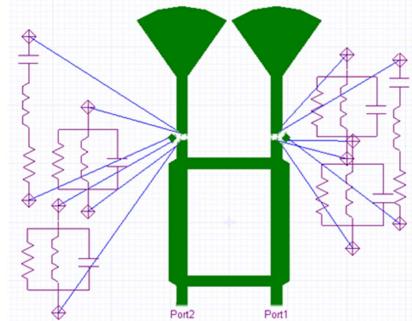


Fig. 5. Phase shifter model.

Phase variation and insertion loss are shown in Fig. 6a and Fig. 6b, respectively. The phase shift ranges around 198 degree over capacitances achievable with the varactors. At first glance, the insertion loss in Fig. 6b may seem high, but lossy

FR-4 dielectric was used in this model. The loss is expected to be reduced when using the final RO4003C substrate. Fig. 7 shows the assembled phase shifter.

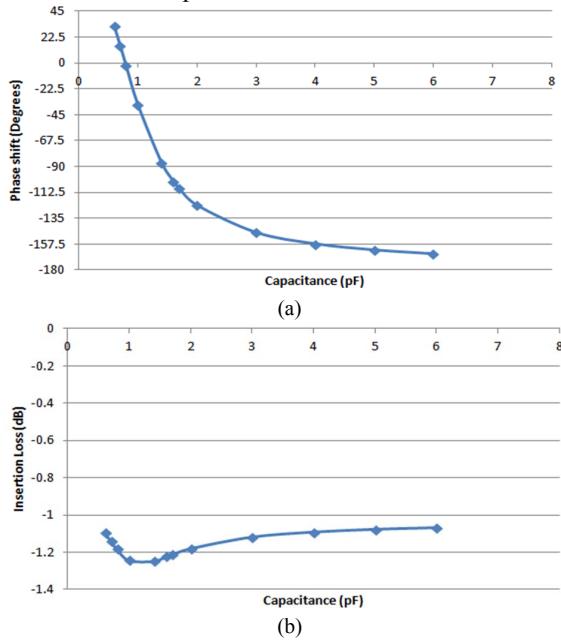


Fig. 6. Phase shift simulation of the variable phase shifter (a), and transmission coefficient in dB (b) versus capacitance.

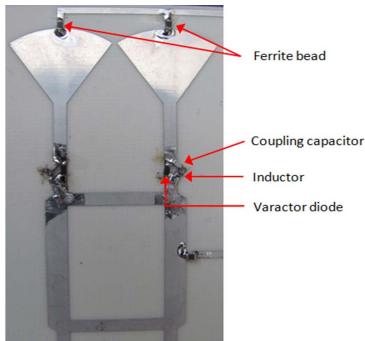


Fig. 7. Assembled variable phase shifter.

D. Antenna System

With the antenna and feed network components designed, a few more features are added to complete the design. First, decoupling capacitors are added between the variable coupler and the phase shifter to isolate the DC biases. Also, a capacitor was added at the input port as the network analyser is sensitive to applied DC biases. Second, traces were added to all of the

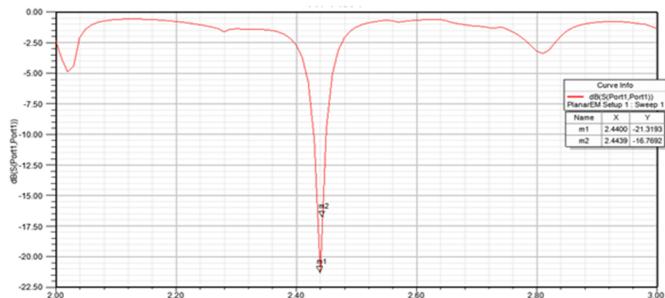


Fig. 8. Input reflection coefficient of the antenna system shown in Fig. 2.

components needing a DC bias, broken approximately every quarter wavelength to avoid resonances or interfering features. In the gaps, ferrite beads are placed to prevent RF coupling but allow DC current to flow. All the DC bias lines connect to microwave traces perpendicularly to avoid unwanted coupling between traces.

Simulations of the complete PCB are performed to make sure the system performs as expected. First, the reflection coefficient is computed to ensure all the traces are connected properly. Fig. 8 is representative of the resulting reflection coefficient. Its value is low around the design frequency as expected.

Another format in which simulation results can be visualized is through field overlays. For example, Fig. 9 shows the current distribution on the board at different settings. Blue indicates no current while red indicates large currents. Fig. 9a

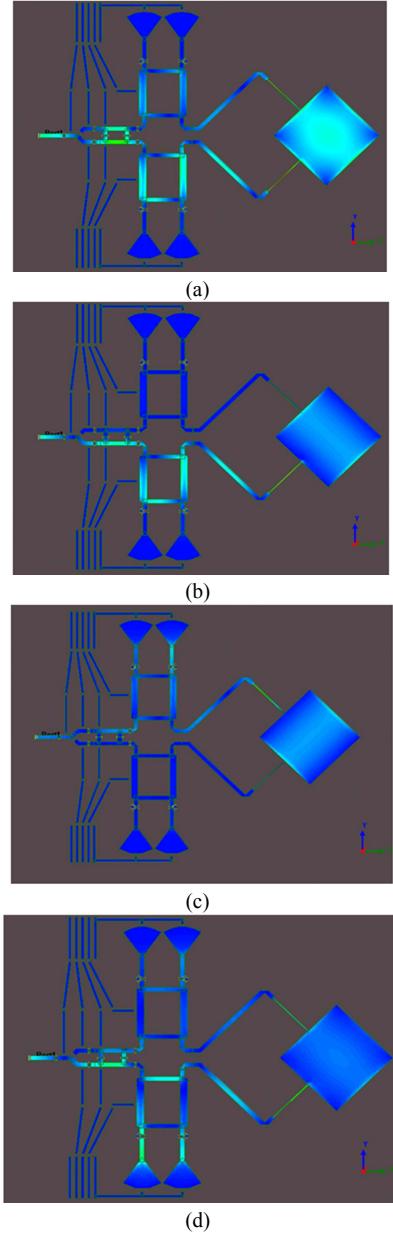


Fig. 9. Current distributions for different polarizations; (a) circular, (b) linear, (c) perpendicular linear, (d) diagonally.

demonstrates the configuration for circular polarization, Fig. 9b for linear polarization in one direction and Fig. 9c for linear polarization in the perpendicular direction. Finally, Fig. 9d shows linear polarization in the diagonal.

III. RESULTS

Fig. 10 shows a photograph of the assembled prototype on RO4003C substrate with all components, devices and input coaxial connector in place. Also, soldered to the board were 0.1" header connectors for easy connection to the DC bias lines. These connectors are not clearly seen as they are bent backwards. They connect to control circuitry that allows the polarization of the antenna to be controlled by a PC via a USB port. The entire system setup for testing, including a microcontroller and control board for diode dc biasing, is depicted in Fig. 11. The control circuitry is powered separately by a bench power supply at 5 V. This board is fed PWM signals from the micro-controller which is in turn commanded via USB by a PC.

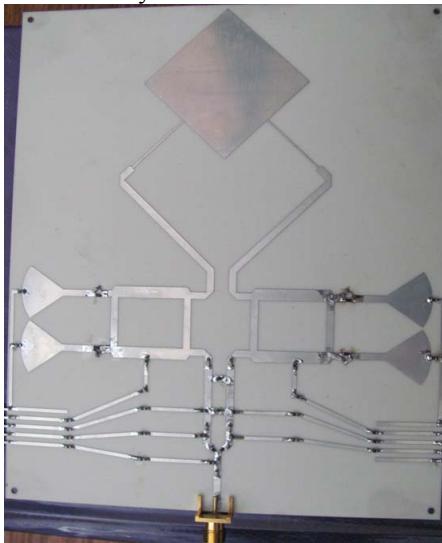


Fig. 10. Prototype of the microstrip antenna system for arbitrary polarization reconfigurability.

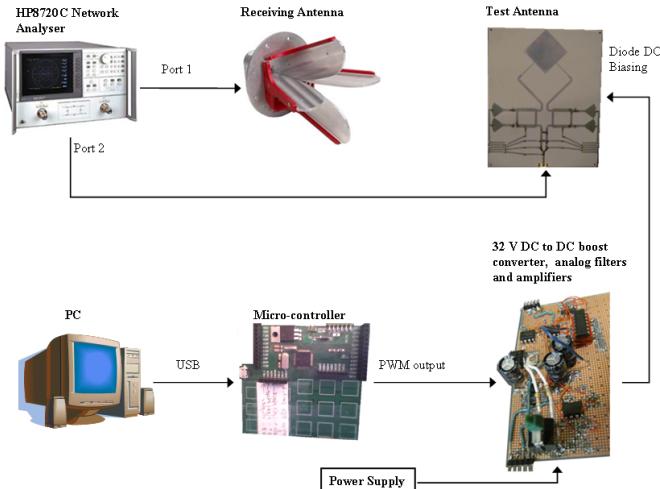


Fig. 11. Reconfigurable microstrip antenna test setup.

A snap shot of the input reflection coefficient, as seen on the vector network analyzer, with the left PIN diode switched on is depicted in Fig. 12. The reflection coefficient is very similar to the simulated result, albeit slightly worse because of the contributory reflections from other components. Most importantly, the reflection coefficient is always below -10 dB throughout the operating range of the power divider varactors between 0.25 pF to 0.95 pF.

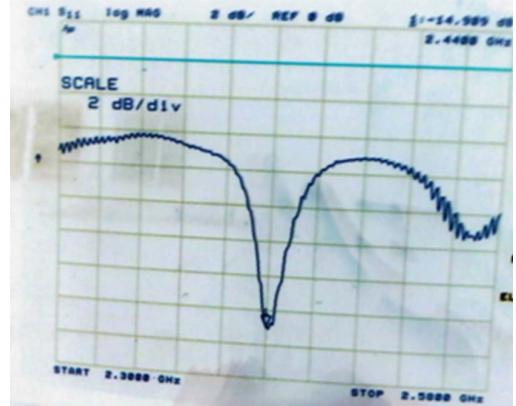


Fig. 12. Snap shot of the measured input reflection coefficient.

To measure the horizontal and vertical components of the wave, the antenna is tilted to the right at 45 degrees with respect to a quad-ridged horn test antenna. In this position, the left feed powers the horizontal polarization component and the right feed powers the vertical one. In the following two figures, the varactor capacitance inside the variable coupler is varied from the minimum to the maximum. Note that greyed-out regions represent invalid operation but shown to give context.

In the first case, shown in Fig. 13, the left PIN diode is turned on corresponding to a change in polarization from horizontally linear to circular. Recall that the two outputs of the variable coupler are approximately 90 degrees out of phase, which is the reason equal power outputs result in circular polarization. An isolation of 3.9 dB occurs when the horizontal component is fully turned on.

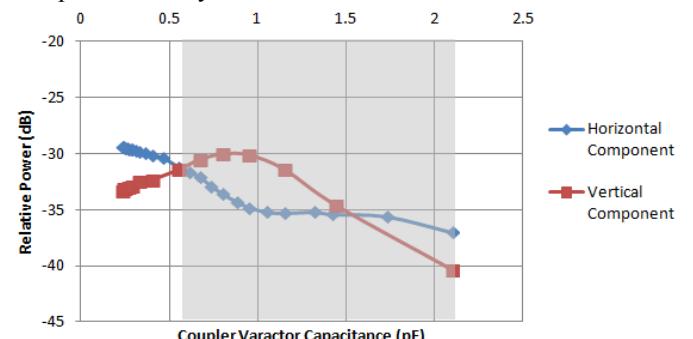


Fig. 13. Measured polarization sweep from horizontal to circular.

In the second case, shown in Fig. 14, the right PIN diode is turned on corresponding to a change in polarization from vertically linear to circular. The measured diagonal component is also shown to better understand the transmitted polarization. Using the diagonal component, circular polarization and linear polarization with a 45 degree tilt can be distinguished. An isolation of 8.8 dB occurs when the vertical component is fully turned on.

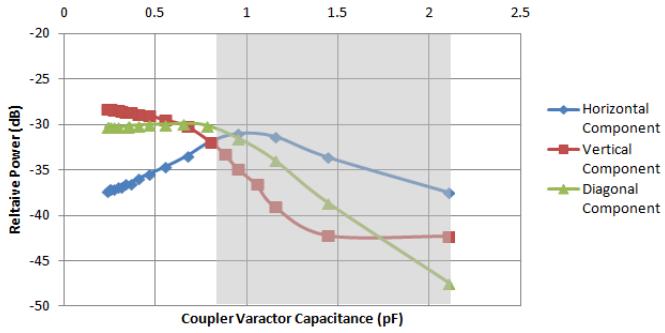


Fig. 14. Measured polarization sweep from vertical to circular.

Both polarization sweeps clearly show a change in polarization as expected. Equal power in the horizontal and vertical components occurs at a capacitance of 0.8 pF which is slightly lower than the simulated result of 0.9 pF but is of little concern. Also, in Fig.14, the diagonal component is fairly constant throughout the valid range of operation which ends at 0.9 pF. The diagonal is constant, as expected, because the two orthogonal components are always being fed 90 degree apart and the total power delivered is constant.

Fig. 14 indicates a higher diagonal component at a capacitance of 0.8 pF. At this circular polarization setting, the diagonal component should have the same magnitude as the horizontal and vertical component. Instead, there is a substantial difference of 1.8 dB indicating an elliptical polarization. These discrepancies are mainly attributed to asymmetry in the measurement setup and the soldering to the two phase shifters. The functionality of the phase shifters were not confirmed at the time of writing but the additional flexibility they offer would allow phase compensation and improved performance.

IV. CONCLUSIONS

A reconfigurable patch antenna capable of dynamically changing its polarization to any configuration is presented. The

device is purely solid state, controlled by electronic means via a computer application and USB link. The feed system consists of a PIN diode switch, a variable power divider, two variable phase shifters and two impedance transformers. Reconfigurability at 2.44 GHz is demonstrated, albeit with some caveats. The first caveat is the non-ideal isolation of 3.9 dB and 8.8 dB between individual polarization states. This is attributed mainly to the power divider that exhibited some coupling even if the coupled port is set to full isolation. The second one is the asymmetry which is partly due to different soldering of the two phase shifters but is mainly attributed to an asymmetric and equipment-related measurement setup. The third one is the lack of testing the phase shifters which would show the full reconfiguration capability of the antenna. Regardless, the principal of operation is sound, and proof of concept is demonstrated.

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