

A Reconfigurable Microstrip Patch Antenna with Polyphase Filter for Polarization Diversity and Cross Polarization Filtering Operation

Lakhdar Zaid, Albane Sangiovanni

Abstract—A reconfigurable microstrip patch antenna with polyphase filter for polarization diversity and cross polarization filtering operation is presented in this paper. In our approach, a polyphase filter is used to obtain the four 90° phase shift outputs to feed a square microstrip patch antenna. The antenna can be switched between four states of polarization in transmission as well as in receiving mode. Switches are interconnected with the polyphase filter network to produce left-hand circular polarization, right-hand circular polarization, horizontal linear polarization, and vertical linear polarization. Additional advantage of using polyphase filter is its filtering capability for cross polarization filtering in right-hand circular polarization and left-hand circular polarization operation. The theoretical and simulated results demonstrated that polyphase filter is a good candidate to drive microstrip patch antenna to accomplish polarization diversity and cross polarization filtering operation.

Keywords—Microstrip patch antenna, polyphase filter, circular polarization, linear polarization, reconfigurable antenna.

I. INTRODUCTION

POWERFUL modern wireless communication systems require to be multistandard with the devices circuits capable of changing the working frequency, gain, linearity, filtering properties, but also with the diversity of antennas such as the polarization, the pattern, and the frequency agility. Microstrip Patch Antennas (MPA) have the advantage of low profile, lightweight, and can integrate electronics devices for radio communication systems. Polarization diversity has created a great interest to avoid the drawbacks caused by multipath effect [1]. A dual circularly polarized MPA can be accomplished by generating four coupling points in phase quadrature [2]. The left or right circularly polarized operation is done by changing the feed port of the microstrip line through a cross shaped aperture in the ground plane. That allows coupling between the feed microstrip line placed under the ground plane and the patch antenna above the ground plane [3], [4]. Other MPA have the functions of switchable pattern and polarization by square-ring radiating patch and shorting walls [5]. The shorting walls are connected to each edge of the square-ring patch through one pin diode. Two complementary patterns (conical and broadside) and dual orthogonal linear polarizations are achieved by controlling the states of four pin diodes [6]. Bias polarities and pin diodes states control the antenna properties for right-hand circular

polarization (RHCP), left-hand circular polarization (LHCP), or linear polarization [7]. Switches are often used to reconfigure MPA for radiation pattern selectivity and polarization diversity [8]. The polarization can also be controlled by the input signal of the antenna, and no separate Radio Frequency (RF) switch is required [9]. Some antennas combine switchable polarization and frequency agility realized with pin diodes and varactor diodes [10] or RF Microelectrical-Mechanical (MEMS) [11]. Other devices use liquid crystal based tunable coupled line for reconfigurable polarization antenna [12], [13]. The mutual coupling effect with high isolation results in a broadband dual-polarization antenna composed of two orthogonally situated dipoles [14].

This paper demonstrates that Polyphase Filter (PPF) is a good candidate to accomplish a reconfigurable MPA with polarization diversity and cross polarization filtering operation. The feasibility of the proposed solution is investigated theoretically and simulated results are presented and discussed. The MPA is directly connected to the PPF which supplies the four 90° phase shift outputs for the circular polarization ability. In transmission mode, the outputs of PPF provide a feed network of four sources with equal amplitude and quadrature of phase. Switches are interconnected with the PPF network to produce LHCP, RHCP, Horizontal Linear Polarization (HLP) and Vertical Linear Polarization (VLP). The additional advantage of using PPF is image rejection due to its filtering capability [15]. Actually, receiver or transmitter systems performances can be improved in terms of filtering properties simultaneously by the PPF while driving the antenna in circular polarization (RHCP or LHCP). In this paper, the polarization diversity of a MPA with a PPF, and filtering operation, is presented. Section II presents the operation principle of the PPF associated to a MPA. Simulation results and theoretical investigation are presented in section III.

II. POLYPHASE ANTENNA AND OPERATION PRINCIPLE

The schematic of the proposed reconfigurable MPA with PPF is shown Fig. 1. A differential RF signal (0° - 180°) is applied to one section PPF. The purpose of this PPF is to generate the four outputs signals $V_{out_1,2,3,4}$ in quadrature of phase. The polarization agility of the antenna is performed through the command $C_{1,2,3}$ which drives the output PPF switches. A passive PPF is composed of four couple of resistors and capacitors (RC) [15]. The proposed application uses a balanced input signal, consequently the four PPF inputs

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$V_{in_1,2,3,4}$ are connected by pair as in Fig. 1 (a). The four quadrature of phase outputs $V_{out_1,2,3,4}$ are directly connected to the MPA through the six switches $S_{1,2,3,4,5,6}$. To achieve the antenna polarization diversity, the switches $S_{1,2,3,4,5,6}$ control the TM_{10} , TM_{01} modes of a square MPA [2].

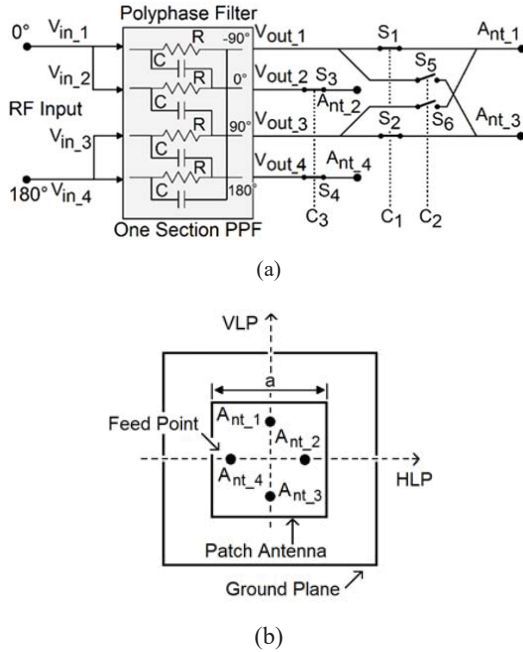


Fig. 1 Schematic of the proposed reconfigurable MPA with PPF for polarization diversity. One section PPF with six Switches $S_{1,2,3,4,5,6}$ (a). MPA feeding points $A_{nt_1,2,3,4}$ with HLP and VLP orientation (b)

The ability of linear and circular polarization is achieved by the phase control of the four $Ant_{1,2,3,4}$ signals that directly drive the antenna. The switches $S_{1,2}$ and $S_{5,6}$ allow 180-degree phase shift of the MPA feed, for RHCP or LHCP operation. Circular and linear polarization configurations are presented in Table I according to the switches position. The transmitted antenna polarization is presented versus output PPF switches state $S_{1,2,3,4,5,6}$. Circular polarization is achieved while all the outputs $Ant_{1,2,3,4}$ of the PPF drive a RF signal to antenna. In this case, the antenna is operated in LHCP when the switches $S_{1,2,3,4}$ are closed, and the switches $S_{5,6}$ are open. The RHCP is also obtained from the previous case by closing the switches $S_{5,6}$ while opening the switches $S_{1,2}$. LHCP or RHCP are accomplished because the switches $S_{1,2}$ and $S_{5,6}$ are able to change with 180-degree phase shift the RF signals Ant_1 and Ant_3 applied to the antenna. Consequently, the relative 90-degree phase shift of PPF outputs $Ant_{1,2,3,4}$ is also inverted which brings about the RHCP or LHCP operation.

The MPA can transmit HLP and VLP independently of the switches state $S_{5,6}$ which remain open. The antenna works in HLP when the switches $S_{1,2}$ are open, and the switches $S_{3,4}$ are closed. The VLP ability is performed when the switches $S_{1,2}$ are closed, and the switches $S_{3,4}$ are open.

TABLE I
RELATION BETWEEN SWITCHES CONFIGURATION $S_{1,2,3,4,5,6}$ AND TRANSMITTED ANTENNA POLARIZATION

Transmitted Polarization	output PPF switches		
	$S1_S2$	$S3_S4$	$S5_S6$
LHCP	CLOSED	CLOSED	OPEN
RHCP	OPEN	CLOSED	CLOSED
HLP	OPEN	CLOSED	OPEN
VLP	CLOSED	OPEN	OPEN

III. RESULTS AND DISCUSSIONS

To confirm the property of reconfigurable MPA with PPF for polarization diversity, simulation results and implementation properties are discussed. We demonstrated that one section PPF (Fig. 1 (a)) can drive a MPA for transmitter and receiver application. Moreover, advantages of multiple section PPF for filtering operation are also presented and discussed.

A. Quadrature of Phase with PPF

The one section PPF presented in Fig. 1 (a) is simulated with LTspice at 2.4 GHz frequency. Each PPF outputs $A_{nt_1,2,3,4}$ are terminated on a 50 Ω resistor to take into account the input impedance of the matched MPA. All resistors and capacitors of a single PPF section require identical value ($R=50 \Omega$, $C=1,32$ pF in this case). The transient simulations presented in Fig. 2 exhibit the four RF signals $A_{nt_1,2,3,4}$ of the PPF that drive the antenna. The results demonstrate that when a differential signal is applied to a PPF, its outputs provide four signals with equal amplitude and quadrature phase. In this case, it is well-known the MPA drive a circular polarization [16].

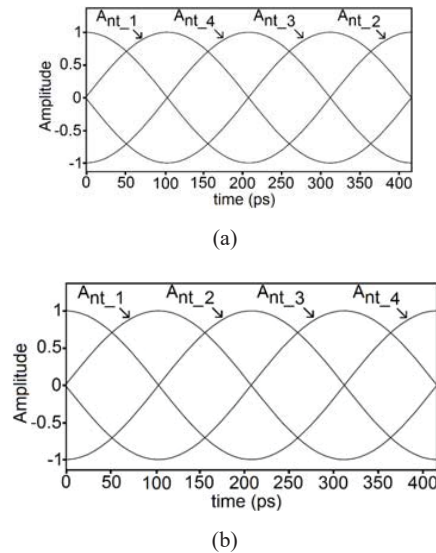


Fig. 2 Output signals $A_{nt_1,2,3,4}$ of the simulated PPF of Fig. 1 (a) at 2.4 GHz. Anticlockwise quadrature sequence $A_{nt_1} \rightarrow 4 \rightarrow 3 \rightarrow 2$ with $S_{1,2,3,4}$ closed and $S_{5,6}$ opened (a). Clockwise quadrature sequence $A_{nt_1} \rightarrow 2 \rightarrow 3 \rightarrow 4$ with $S_{3,4,5,6}$ closed and $S_{1,2}$ opened (b)

When the switches $S_{1,2,3,4}$ are closed while the switches $S_{5,6}$

are opened the PPF drives the anticlockwise quadrature sequence $A_{nt_1 \rightarrow 4 \rightarrow 3 \rightarrow 2}$ as shown in Fig. 2 (a). In this configuration, the antenna as a transmitter is operated in the LHCP. When the switches $S_{3,4,5,6}$ are closed while the switches $S_{1,2}$ are opened, the PPF drives the clockwise quadrature sequence $A_{nt_1 \rightarrow 2 \rightarrow 3 \rightarrow 4}$ as shown in Fig. 2 (b). This state leads the antenna to transmit a RHCP electromagnetic field. The MPA works in linear polarization when only two switches are closed to feed and control the TM_{10} , TM_{01} modes. These modes are driven when two diametrically disposed feed point are excited in phase opposition [11]. The PPF can achieve this task when only the couple of switches $S_{1,2}$ or $S_{3,4}$ are closed. In this case the Figs. 2 (a) and (b) show the PPF provides always two RF signals $A_{nt_2,4}$ and $A_{nt_1,3}$ in phase opposition for respectively HLP and VLP operation.

B. MPA with a Wideband PPF for Filtering Operation

The proposed solution of reconfigurable MPA with PPF for polarization diversity also presents the advantage of filtering properties. As a matter of fact, when the PPF is used to generate the four clockwise quadrature sequence signals $A_{nt_1 \rightarrow 2 \rightarrow 3 \rightarrow 4}$, the transmitted or received signal driven by the opposite quadrature sequence (anticlockwise sequence $A_{nt_1 \rightarrow 4 \rightarrow 3 \rightarrow 2}$) is filtered by the PPF [15]. Reciprocally, when the PPF and the antenna are used to drive the four anticlockwise quadrature sequence signals $A_{nt_1 \rightarrow 4 \rightarrow 3 \rightarrow 2}$, in the same way, the PPF is able to filter the signal transmitted or received by the antenna in this case the clockwise sequence $A_{nt_1 \rightarrow 2 \rightarrow 3 \rightarrow 4}$. The PPF property is already used in radiofrequency receiver architectures to suppress the image frequency channel [15].

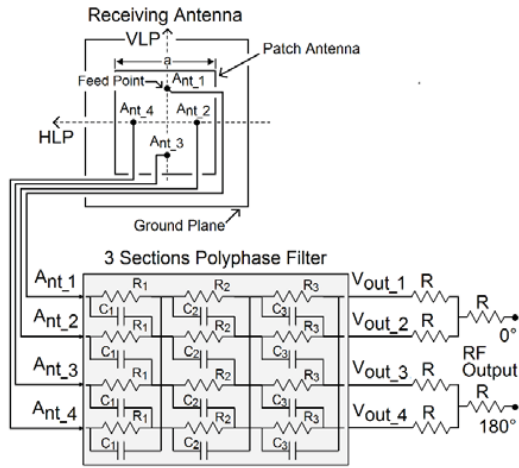


Fig. 3 Four output MPA signals driving a 3-section PPF with differential output ($R_1=65 \Omega$, $R_2=72 \Omega$, $R_3=80 \Omega$, $C_1=C_2=C_3=1 \text{ pF}$)

But another interesting property of PPF that we investigate in this paper is its filtering property when the antenna is circularly polarized. Let us consider the three sections based ideal PPF fed by a receiving square MPA presented in the Fig. 3. The circular polarized electromagnetic field received by the antenna is converted to an electrical signal directly applied to

the PPF. The ideal PPF with three sections in Fig. 3 is simulated with LTspice from 1 to 6 GHz with four input signals in quadrature of phase for the antenna behavior. The four PPF output signals $V_{out_1,2,3,4}$ are also combined with six resistors (of value R) like in Fig. 3 to obtain a differential signal. When the quadrature of phase sequence $A_{nt_1 \rightarrow 4 \rightarrow 3 \rightarrow 2}$ from the MPA corresponds to the desired circular polarization, then the PPF provides an output signal. In this case, the three sections (R_1C_1 , R_2C_2 , R_3C_3) of the PPF output drive the anticlockwise quadrature sequence $A_{nt_1 \rightarrow 4 \rightarrow 3 \rightarrow 2}$ with low attenuation as shown in Fig. 4. On the contrary, the clockwise quadrature sequence $A_{nt_1 \rightarrow 2 \rightarrow 3 \rightarrow 4}$ transmitted by the antenna to the PPF is also filtered as shown in Fig. 4. This operation is due to the rejection PPF bandwidth thanks to the three poles $f_{p1,2,3}$ also called notch. Each frequency notch is determined by $f_{px} = 1/2\pi R_x C_x$, and the more section of PPF we have the bigger is the bandwidth and the better is the quadrature of phase. The circular polarization operating property (RHCP or LHCP) of the antenna is changed by permuting the Ant_4 signal with Ant_2 signal (Fig. 3).

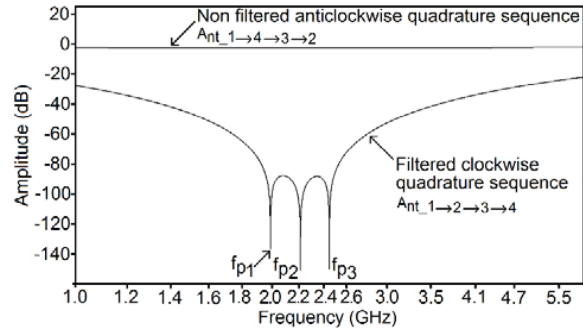


Fig. 4 Differential output of the simulated 3-section PPF of Fig. 3 with clockwise and anticlockwise quadrature sequence input signals

A passive MPA is able to work in RHCP as LHCP and convert the received electromagnetic field into an electrical signal. The antenna and PPF coupling allows only the device to provide a RHCP or LHCP at the PPF output due to its particular transfer function (Fig. 4). Consequently, an antenna working in circular polarization mode associated to a PPF may filter the cross polarized signal and deliver a balanced signal. The filtering property of the PPF could be used to further optimize the antenna performance of radiofrequency receiver.

C. PPF and MPA Implementation

The total transfer function of the PPF in Fig. 4 is described as the sum of the clockwise and anticlockwise transfer function respectively noted $H(\omega)$ and $H(-\omega)$. Consequently, the PPF output signals are

$$V_{out_1} = \frac{V}{2} [H(\omega) + H(-\omega)] \quad V_{out_2} = -j \frac{V}{2} [H(\omega) - H(-\omega)]$$

$$V_{out_3} = -\frac{V}{2} [H(\omega) + H(-\omega)] \quad V_{out_4} = j \frac{V}{2} [H(\omega) - H(-\omega)]$$

As the PPF in Fig. 1 (a):

$$H(\omega) = \frac{V_{out,x}}{V_{in,x}} = \frac{1-\omega RC}{1+j\omega RC} \quad (1)$$

$$H(-\omega) = \frac{V_{out,x}}{V_{in,x}} = \frac{1+\omega RC}{1+j\omega RC} \quad (2)$$

$V_{out,1}(\omega)$ and $V_{out,3}(\omega)$ are in opposite phase like $V_{out,2}(\omega)$ and $V_{out,4}(\omega)$, and the couple $[V_{out,1}(\omega), V_{out,3}(\omega)]$ and $[V_{out,2}(\omega), V_{out,4}(\omega)]$ are in quadrature of phase. Let us consider only two signals in quadrature of phase V_I (In phase) and V_Q (Quadrature of phase) as

$$V_I = V_{out,1} - V_{out,3} = V_I(\omega) = V[H(\omega) + H(-\omega)] \quad (3)$$

$$V_Q = V_{out,2} - V_{out,4} = V_Q(\omega) = -jV[H(\omega) - H(-\omega)] \quad (4)$$

The PPF implementation is mainly dependent on the operating frequency. For better performance, the four output PPF signals need to be equal amplitude with good quadrature of phase for V_I and V_Q . The ratio P of V_Q and V_I is expressed by replacing (1), (2) into (3) and (4)

$$P = \frac{V_Q(\omega)}{V_I(\omega)} = j\omega RC \quad (5)$$

and

$$\frac{\Delta P}{P} = \frac{\Delta \omega}{\omega} + \frac{\Delta R}{R} + \frac{\Delta C}{C} \quad (6)$$

Equation (6) shows the precision of output PPF signals is very dependent on mismatch of resistors and capacitors. One section PPF (Fig. 1 (a)) gives output signals of equal amplitude with a quadrature of phase only near the considered frequency pole $f_p = 1/2\pi RC$. That limits PPF with one section to low bandwidth applications. For wideband operation, a PPF with multiple section is required (Fig. 3) to enlarge the bandwidth (Fig. 4) by new frequency pole adjunction. To avoid loss due to passive component of PPF, amplifier implementation between the PPF RC sections may be required [17]. The PPF implementation is mainly limited by RC value mismatch of each PPF section and consequently the parasitic resistor and capacitor issue in PPF wire connection design too. The performances of the reconfigurable MPA with PPF also depend on the switches types. Radio frequency signal leakage needs to be minimized for better polarization purity and some components like MOS transistor, P-I-N diode [2] or RF MEMS may be used to fulfill the switch function [11].

IV. CONCLUSION

A PPF associated to a MPA can perform polarization diversity and cross polarization filtering operation. The simulated results demonstrate that a PPF is able to feed and control the polarization of a MPA. Electronic components used such as switches combined to a PPF allow a dynamic change of polarization as linear horizontal and vertical polarization but also right and left circular polarization. The simulated PPF transfer function exhibits a rejection bandwidth

property for the circular polarization operating antenna. This PPF capability may be used to filter the cross polarized signal received by the antenna in RHCP or LHCP operation. Theoretical investigation shows the PPF design is particularly sensitive to mismatch of passive components like resistors and capacitors of each PPF section. In the same way, parasitic resistors and capacitors from wires connection between the RC components of the PPF layout need to be carefully taken into account in the final implementation design. Consequently, the PPF is very suitable in antenna application for modern receiver and transmitter devices.

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