Design and Analysis of Miniaturized Reconfigurable Multifunction Microstrip Array Antenna for Communication and Radar Applications

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Abstract—The reconfigurability may be required in operating frequency, radiation pattern and/or polarization of the antenna. Application areas that drive the development of reconfigurable antennas include multifunction wireless devices, WLAN, multiple-input multiple-output (MIMO), ultra-wideband (UWB) systems, anti-jamming and secure communication. Recent technologies enable electronic and RF circuits in radar and communication devices to be miniaturized and become physically smaller in size. Antenna design has been one of the key limiting constraints to the development of small communication terminals, next generation wireless communication and radar requirements of multi-band and multi-function operation. In this paper, design of miniaturized reconfigurable multifunction microstrip array with single-pole double-throw (SPDT) transmitter/receiver (T/R) switch has been introduced and investigated. The entire proposed array antenna has been evaluated using a commercial software. The final proposed design has been fabricated and the radiation characteristics have been illustrated using network analyzer to meet the requirements for multifunction communication and radar applications.

Keywords— Microstrip antenna; reconfigurable multifunction array; SPDT-T/R switch; communication and radar applications.

I. INTRODUCTION

Reconfigurability for an antenna can be defined as its capacity to change the fundamental properties, e.g., operating frequency, impedance bandwidth, polarization, radiation patterns or a combination of a few of these characteristics. A single multifunction antenna can replace a number of single-function antennas, thereby reducing overall size, cost and complexity of the antenna system while improving total performance. Recently, reconfigurable antennas have gained tremendous research interest for many different applications, e.g., cellular radio system, radar system, satellite communications, airplane and unmanned airborne vehicle (UAV) radar, smart weapon protection. In mobile and satellite communications, reconfigurable antennas are useful to support large number of standards (e.g., UMTS, Bluetooth, WiFi, WiMAX, DSRC), to mitigate strong interference signal and to cope with changing environmental conditions. On the other hand, in radar applications, reconfigurability at antenna level is often needed for multi-functional operation. This feature is achieved by utilizing different radiating elements for different antenna modes and then integrating them into the same array structure [1], [2]. Microstrip antennas are particularly suitable for use as antenna subsystem or system. It is an antenna having all of the necessary components such as, a feeding, an antenna element, T/R switch, integrally provided on a monolithic substrate, thus producing compact, low cost, multi-function antenna [3], [4]. The modern radar concept explored the development of multi-function wideband arrays capable of simultaneous and time interleaving, electronic warfare, and communications functions. This necessitated the need of frequency independent wideband antennas [5], [6]. In modern communication and radar systems, SPDT-T/R switch is a block in a transmitter/receiver (T/R) module that routes antenna (ANT) to either transmitter (TX) or receiver (RX) [7]-[12]. So, it is a quite challenge to have a small antenna which can support multi-band and multi-function requirements. In addition to the multi-band and multi-function requirements, isolation between antennas is also a critical parameter in many practical applications. To serve various applications using only one antenna, the multifunction array antenna is one of the promising solution. In this paper, study and design of miniaturized reconfigurable multifunction microstrip array with SPDT-T/R switch has been introduced. The proposed array antenna structure has been designed using Rogers RO3210 substrate with (εr = 10.2, tanδ = 0.003) and thickness of 1.27 mm. The radiation characteristics of the proposed structure are obtained and analyzed using HFSS simulator [13] to demonstrate the performance. The proposed integrated microstrip array antenna has been fabricated and measured at the frequency band from 100 MHz to 10 GHz using Agilent FieldFox network analyzer (NA), N9918A.

II. THE PROPOSED MULTIFUNCTION MICROSTRIP ARRAY ANTENNA COMPONENTS SIMULATION RESULTS

A. Antenna Elements

The rectangular microstrip patch antennas with inset feed have been introduced and analyzed [14], [15]. The conducting feed strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of
fabrication and simplicity in modeling as well as impedance matching [14], [15]. The proposed antennas have been designed around the frequencies 3 and 5 GHz. The 3D and top views of the proposed antennas, and $S_{11}$ in dB versus $f$ in GHz are shown in Figs. 1 and 2, respectively.

**B. SPDT-T/R Switches**

In a typical transceiver system, primary aims are to direct high power RF signal from TX to ANT while preventing leakage of that large signal into more sensitive front-end of RX [7]-[9]. PIN diodes mainly have two states: forward bias and reverse bias. At forward bias, the PIN diode behaves like a small resistor with a series inductance. At reverse bias, the PIN diode behaves like a capacitance in parallel with a high resistor. From SPDT-T/R switch behavior, it was found that, in transmit mode (RF signals go through TX to ANT), the PIN diodes are turned ‘OFF’. Then, TX coupled-resonator becomes all-pass response while in the receive arm, the PIN diodes are turned ‘ON’. Then, the RX coupled-resonator becomes band-stop response.

Refer to reference [8], each proposed antenna has an identical SPDT-T/R switch with PIN diode structure, as shown in Fig. 3. Hence, the additional isolation can be obtained and also the receive arm becomes absorptive port. The same operation can be obtained in the receive mode (RF signals go through ANT to RX) when PIN diodes are turned ‘ON’ in the transmit arm; and PIN diodes are turned ‘OFF’ in the receive arm.
Numerical simulation using HFSS simulator is used to obtain the $S$-parameters of the SPDT-T/R switch structures, as shown in Fig. 4. Fig. 4 shows simulated $S$-parameter data of the two sides of SPDT switch networks. The basic behavior of the SPDT switch shows wideband RF properties in terms of low transmission losses ($S_{21} \leq -1$ dB, ON state) and high isolation ($S_{21}$, OFF state) over a different frequency range. The reconfigurable using PIN diode is designed to satisfy that the SPDT can be switched between ‘ON’ and ‘OFF’ states.

C. Array Antenna Unit cells and Wilkinson Power Divider

The array antenna unit cell composed of the proposed rectangular microstrip patch antenna integrated with SPDT-T/R switch. The proposed designs structure and $S$-parameters simulated results are shown in Figs. 5 and 6, respectively.

From Fig. 6, it was found that the proposed fully integrated antennas and SPDT-T/R switch with PIN diode have different high isolation up to -65 dB. The developments in the design of band reject filters are essential to meet the ever increasing demands on suppression of unwanted signals and miniaturization of microwave systems. The proposed SPDT switch provides two state of operation under two conditions. The first condition is that the SPDT will produce low transmission losses when the PIN diodes are turned ‘ON’. The second condition is that the SPDT will produce high isolation when the PIN diodes are turned ‘OFF’. Also, the power divider is one of the key components in microwave circuits, and is widely used in the feeding networks of an antenna array.
Among the power dividers, the Wilkinson power divider is frequently used [16]. It can be made with arbitrary power division with equally split 3dB each port and microstrip line between the two output branches is equivalent to the resistor, as shown in Fig.7.

III. THE PROPOSED MULTIFUNCTION ARRAY ANTENNAS
EXPERIMENTAL RESULTS

The proposed miniaturized multifunction array antenna is composed of two different antenna unit cells and Wilkinson power divider [4], [8]. So, there are four optimal different multi-function array antenna structures combination, as shown in Figs. 8 to 11. Photograph of the proposed different fabricated multifunction antenna array structures at antenna laboratory and the radiation characteristics, such as radiation patterns, total electric far field and the measured $S_{11}$ in dB of the proposed design can be analyzed with network analyzer are shown in Figs. 8 to 11.
From Figs. 8 to 11, an alternative designs was found that could be suitable for providing multi-frequency operation antennas, which include wideband, multiband, and reconfigurable configurations. The wideband antennas can serve over a large bandwidth but they receive noise at all out-of-band frequency ranges and can potentially interfere with adjacent operation frequency bands. The multiband antennas are more popular for multi-frequency operations as these are designed to reject any received noise at all out-of-band frequency ranges. Hence, they provide a better S/N performance when compared to wideband antennas. Reconfigurable antennas, introduced in this paper, are
tailored to reject the noise over all the bands that are not in use, which should lead to a significant performance enhancement.

IV. CONCLUSIONS

In this paper, the integrated miniaturized reconfigurable multifunction microstrip array antennas with SPDT-T/R switch and PIN diode have been introduced, fabricated and analyzed. The measured radiation characteristics have been introduced to illustrate the excellent performance with multi-frequency operations to serve different applications, such as second generation (2G), distributed control system (DCS), personal communication service (PCS), third generation (3G), advanced wireless solutions (AWS), universal mobile telecommunications service (UMTS), fourth generation (4G), long term evolution (LTE), fifth generation (5G), LTE-Advanced, LTE-B, high speed packet access (HSPA), wireless fidelity (Wi-Fi), wireless and radar. The proposed multifunction array antennas have low-cost, low-power and high performance to meet the requirements for multifunction communication and radar applications.

REFERENCES


