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Author(s): Abusitta, M.M., Zhou, D., Abd-Alhameed, R.A. and Excell, P.S.

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Design of Controlled RF Switch for Beam Steering Antenna Array

M. M. Abusitta, D. Zhou, R. A. Abd-Alhameed, and P. S. Excell
 Mobile and Satellite Communications Research Centre, University of Bradford
 Richmond Road, Bradford, West Yorkshire, BD7 1DP, UK

Abstract— A printed dipole antenna integrated with a duplex RF switch used for mobile base station antenna beam steering is presented. A coplanar waveguide to coplanar strip transition was adopted to feed the printed dipole. A novel RF switch circuit, used to control the RF signal fed to the dipole antenna and placed directly before the dipole, was proposed. Simulated and measured data for the CWP-to-CPS balun as well as the measured performance of the RF switch are shown. It has demonstrated the switch capability to control the beam in the design of beam steering antenna array for mobile base station applications.

1. INTRODUCTION

The use of adaptive array antennas for cellular base station application has recently become an active area of research and development [1–3]. Base station antennas normally radiate omnidirectionally or in broad sectors, in which the most of the power is radiated in other directions than toward the user. This causes waste of power and interference for other users. Therefore new versions of base station antennas are now being made to overcome the problem by using antennas that have narrow steerable beams. These can give large increment in capacity, and the possibility of tracking mobile phones or vehicles.

In authors' previous work [4], a set of simple design procedures for beam steering single circular and concentric circular ring antenna arrays was proposed and analyzed theoretically (see Fig. 1). In the paper, the design theory was formulated and the results of the proposed analytical model, validated by a numerical model, were presented. Beam steering was achieved by implementing an ON/OFF system concept to excite only specific elements of the array dipole antenna. In this study, a following-up study was carried out on designing and implementing the RF switch for practically realising the beam steering using the proposed ON/OFF antenna array system. A novel design principle of RF switch, used to control the RF signal fed to each of the antenna elements in an array, was proposed. Moreover, a coplanar waveguide (CPW) to coplanar strip (CPS) transition was employed to feed the antenna element (i.e., printed dipole). Subsequently, performance of the CPW-to-CPS fed dipole antenna controlled by a RF switching circuit for duplex operation was evaluated and verified through hardware realisation. The measured results for the CPW-to-CPS balun and practical performance of the RF switch are shown in this paper.

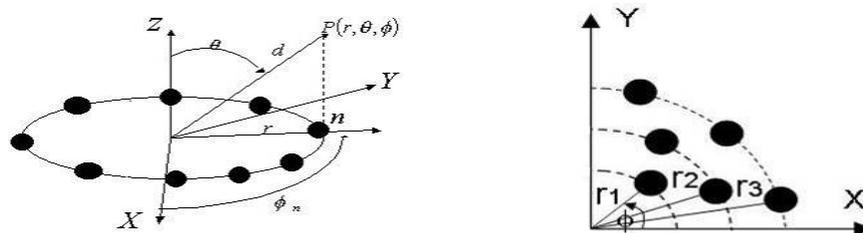


Figure 1: Circular array antenna, single circular ring arrays (left) and concentric circular ring arrays (right).

2. RF SWITCH AND PRINTED DIPOLE ANTENNA FOR BEAM STEERING ANTENNA ARRAY

2.1. CPW-to-CPS Baluns

Two back-to-back CPW-to-CPS balun (see Fig. 2) were examined using ADS simulator, which is based on the Method of Moment [5], in order to evaluate the balun performance such as, insertion and return loss at design frequency (GSM 1800 band). A CPW-to-CPS balun was chosen and

designed for our application due to their several features such as low-loss, ease of fabrication and no need for via holes [6, 7]. The balun structure was mounted on Durioid material ($\epsilon_r = 2.5$, thickness $h = 1.524$ mm, and $\tan \delta = 0.0019$). The measured insertion loss of the fabricated balun, achieved over the operating bandwidth from 1.47 GHz to 2.04 GHz, was found to be less than 1 dB as shown in Fig. 2. It is also noticeable that a reasonable return loss of 10 dB over the same frequency bandwidth. An excellent performance of the magnitude and phase imbalance between the two outputs of a single balun was observed within the intended operating band (the plot is not presented here).

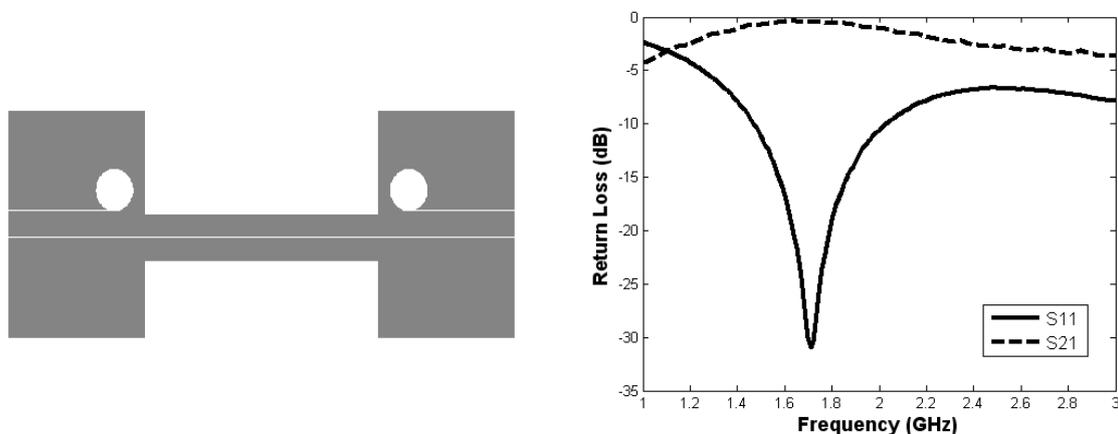


Figure 2: Layout of back-to-back balun (left) and the measured insertion loss and return loss of the balun studied.

2.2. Design of CPW-fed CPS Printed Dipole Antenna

For analysis, performance of the CPW-to-CPS fed dipole antenna was investigated with the aid of ADS. The layout of this dipole antenna is illustrated in Fig. 3, in which the width of the centre conductor is 4 mm and the gap is 0.2 mm. The diameter of the circular slot is 6.4 mm and the antenna length is 78.95 mm which corresponds to slightly less than half the wavelength (i.e., antenna resonates at around 1.84 GHz). For validation, a prototype of such a design was fabricated and tested. Return loss of the fabricated dipole antenna was measured and the result was compared to the data in prediction, as shown in Fig. 3. A bondwire was used to prevent unnecessary higher order modes generated at the discontinuities [8].

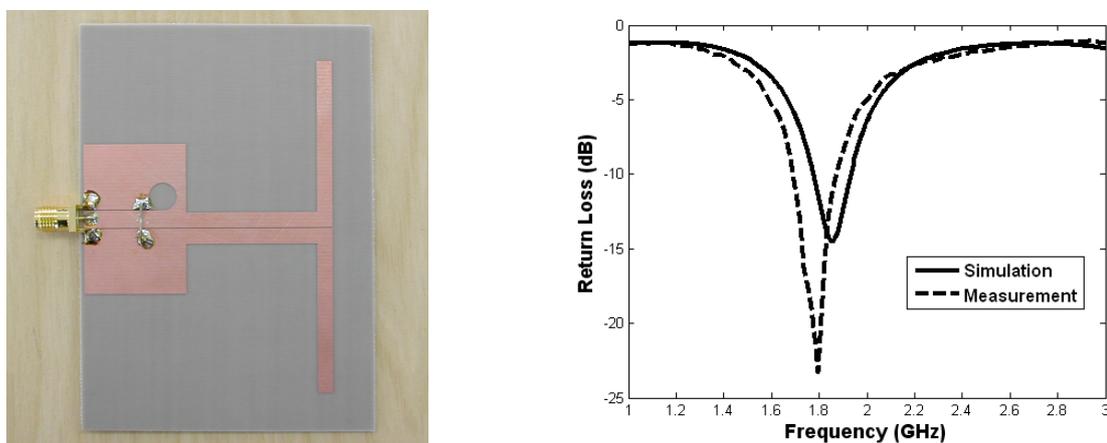


Figure 3: Layout of CPW-to-CPS balun integrated with printed dipole (left) and the measured return loss for this configuration studied (right).

2.3. Design Principle of RF Switch Circuit and Validation

RF switch is the integral part of modern communications system. Their application include well established areas such as radar and emerging areas such as smart (switched beam, phase and adaptive) antennas for terrestrial and satellite communication systems. The fundamental component

in this switching is the operation of the RF p-i-n diode. The switches can be accommodated in the beam forming network or adaptive control beam antenna array systems. An ON/OFF system concept for achieving antenna beam steering was practically implemented by a novel and simple RF switching circuit.

The proposed switch can be used for duplex operation and the circuit diagram is illustrated in Fig. 4. As can be seen, capacitors C1, C2, C3 and C4 are for dc blocking, and three diodes in the circuit with appropriate biasing voltage can be used to provide a function as RF switching. When both V1 and V2 are supplied with positive voltage, RF signal passes through forward biased diode D1 and transmit power to the antenna. There is no signal returned to the path through diode D3 since it is reverse biased. Therefore, the switch is ON and in RF transmission mode. On the contrary, when the power supply is given negative voltage both V1 and V2, diode D1 is in reverse biasing which can be effectively used for blocking the RF signal transmits to the antenna and the reflected RF signal can be eliminated through the diode D2 due to the fact that RF signal is shorted via a 50 ohm resistor (R1) to the ground. In this way, the switch is apparently OFF and in the RF reception mode since only RF signal path through diode D3 is turned on. Thus, a dual mode operation is realized.

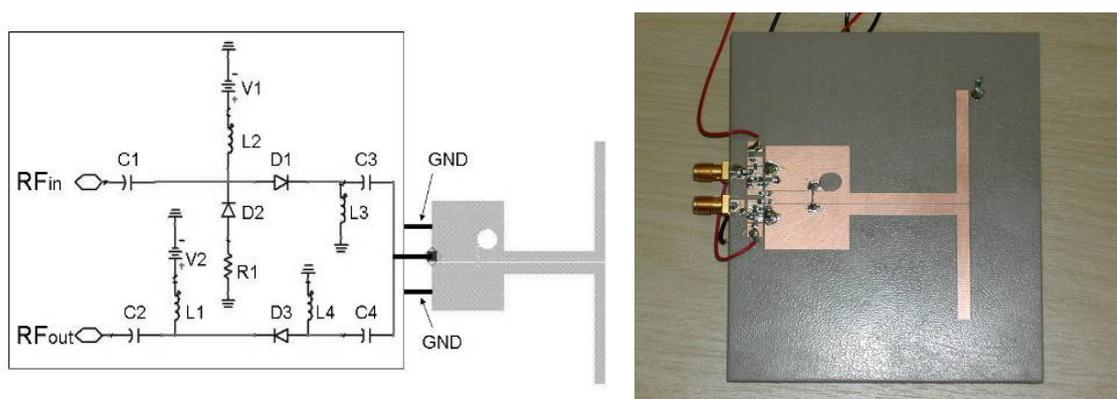


Figure 4: Overall circuit diagram of the RF switch integrated with balun and dipole (left) and prototype (right).

Prototypes of the RF switch integrated with back-to-back balun (see Fig. 5) and RF switch with balun and dipole (see Fig. 4) were fabricated and tested in order to validate the design theory of the proposed RF switching circuit.

The procedure of validation to the RF switch was carried out in two aspects (i.e., 'ON mode' and 'OFF mode'). For the purpose of simplifying the analysis, the fabricated prototype circuit in Fig. 4 was replaced by the back-to-back balun (see Fig. 5) for the evaluation purposes because it is well matched to the 50 ohm at the design frequencies and can be directly connected to the switch as a 50 ohm load. A practical measurement setup for evaluating this RF switch is illustrated in Fig. 5.

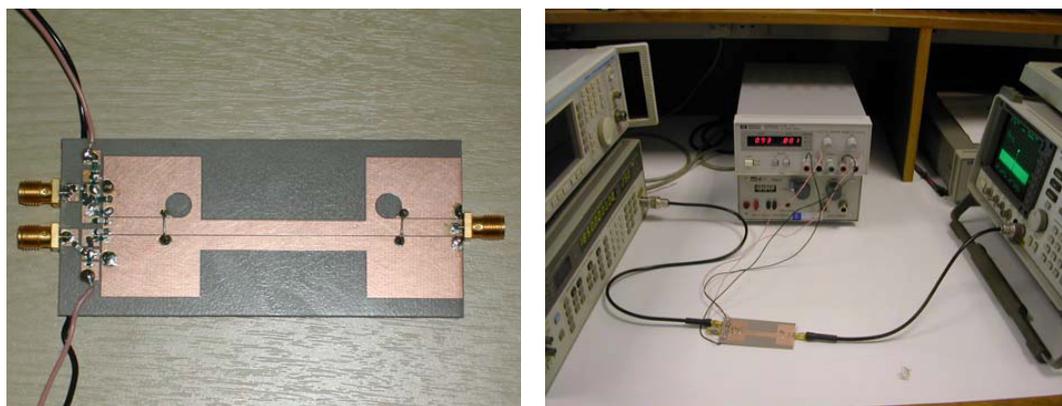


Figure 5: Photograph of the fabricated prototypes of the RF switch integrated with back-to-back balun (left) and measurement setup for RF switch evaluation (right).

To begin testing the ‘ON mode’ for the proposed switch, a positive voltage of 0.93 V was provided to the V1 and V2 (see Fig. 4) and RF signal with power level of -20 dBm at single frequency of 1850 MHz was injected to the RF switch (RF_{in} port) from the signal generator. Subsequently, a RF output power with level of -23.67 dBm (see Fig. 6) from the back-to-back balun was observed on the spectrum analyser. Taking into account of the losses involved from the cable (1.33 dB) and the balun (≤ 1 dB), the total insertion loss on the proposed RF switch was found to be approximately 1.5 dB when the switch is turned on.

On the contrary, in order to test the RF switch performance at ‘OFF mode’, the proposed switch was supplied with a negative voltage of -0.93 V to both V1 and V2 and RF signal with power level of -25 dBm at the same frequency was injected to the back-to-back balun. It is notable that a relatively less power was generated to test the RF switch in the receiving mode as the power level of the received signal is always small in the reception. As a result, a power level of -42.17 dBm was measured at the RF_{in} port. It implies an isolation performance with at least 15 dB was achieved for the proposed RF switch as shown in Fig. 7. It has to be noted that the other port (RF_{out}) in the switch was connected with a 50 ohm load in both cases.

It was found from the forgoing practical investigation that the proposed RF switch exhibits a relatively good performance at ‘ON’ and ‘OFF’ mode. As a consequence, it has demonstrated the capability used as the switch to control beam in the design of beam steering antenna array for mobile base station antennas applications. Therefore, a follow-up study on practical realisation to the mobile base station antenna with enhanced performance using the beam steering antenna array design principle in cooperation with the novel RF switch proposed in this paper will be carried out in the future work.

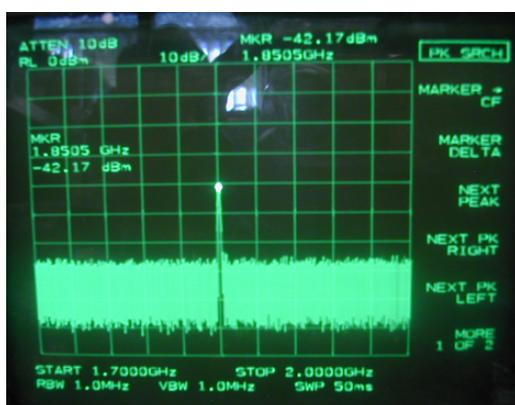


Figure 6: The output of the back to back baluns when the switch mode is off.

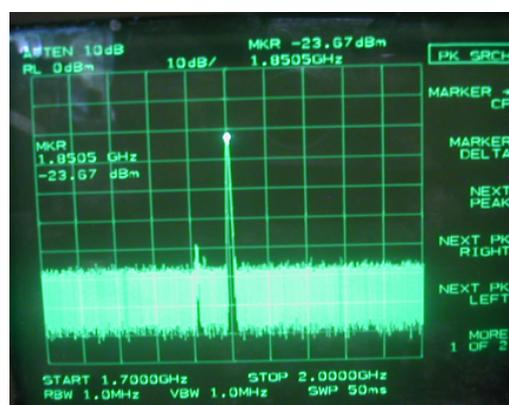


Figure 7: The output of the back to back baluns when the switch mode is on.

3. CONCLUSIONS

In this work, a complete analysis and design of the CPW-fed CPS balanced dipole antenna integrated with a RF switching circuit for antenna beam steering used in mobile base stations, was presented. The CPW-to-CPS balun and the dipole antenna, were investigated and the overall performance of the dipole antenna in collaboration with the RF switching circuit were analysed and evaluated. The predicted results indicating the design goal was well met. This is encouraging for practical implementation of these switchable dipoles in the design of beam steering antennas for the future work.

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