Low-Cost Smart Antenna Using Active Frequency Selective Surfaces

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***Abstract-* Smart antenna is a key technology for advanced wireless systems and one of the most important features of smart antenna is electronically beam scanning or switching. It is highly desirable to reduce the mass, power consumption and cost of smart antennas, as the traditional phased array is always associated with high cost due to the use of many T/R modules and complicated beamforming network (BFN). This paper presents the University of Kent's recent research progress in the field of low-cost smart antenna design using active frequency selective surfaces (AFSS). Firstly, this paper presents a brief review of AFSS based beam-reconfigurable antenna including several recent designs reported by the authors' group. Then, a new high-gain AFSS antenna design with some preliminary results will be presented. This is design achieves higher gain than the reported AFSS antennas. A detailed list of references is given at the end of this paper.**

I. INTRODUCTION

Smart antenna, also known as intelligent antenna or adaptive array, is a key technology for advanced wireless systems, such as satellite communications, inter-satellite links, radars, sensors, mobile communications (5G and beyond), wireless local area networks, global navigation satellite systems (GNSS) and wireless power transfer [1-2]. One of the most important features of smart antenna is electronically beam scanning or switching. Smart antenna enables the wireless systems to achieve the optimum performance and increase the channel throughput by electronically steering its maximum radiation towards the desired directions while forming nulls against interfering sources [3].

Traditional smart antennas are, however, complicated in structure, bulky, power hungry and costly. For commercial applications, it is important to reduce the size, mass, power consumption and cost. Low-cost smart antennas can be achieved by designing innovative antenna system architectures. For example, through using less number of active antenna elements, the number of required T/R modules and RF phase shifters can be reduced, which brings down the cost of the overall antenna system. In recent years, several techniques to reduce the cost of the RF front end of the smart antennas have been reported, including electronically steerable parasitic array radiator (ESPAR) [4-9], retro-directive array [10-11], low-cost multibeam BFN [12-13], active frequency selective surface (AFSS) [14-22], etc. One common feature of these design techniques is that they aim to reduce the number of microwave phase shifters and T/R modules by using different array architectures. Due to the page limits of this conference paper, this paper will focus on the use of AFSS to realize a low-cost beam-reconfigurable antenna.

II. REVIEW OF AFSS BASED BEAM RECONFIGURABLE ANTENNAS

Besides the control circuit, an AFSS based beam-reconfigurable antenna consists of a feed antenna/array and AFSSs. The feed antenna is normally an omnidirectional antenna, such as dipole [14-16], monopole [17-18], dielectric resonator antenna [19], back-to-back patch [20], coaxial collinear antenna [21]. The AFSS screens are electronically configured to operate as a reflector or electromagnetically (EM) transparent to the incident waves. Fig.1 demonstrates the operation principle of the AFSS antenna. Through controlling the operation modes of the AFSS, reflector or EM transparent, the beam of the AFSS antenna can be switched within 360° angle range in the azimuth plane. The Antenna and RF Research team at the University of Kent has been working on AFSS-based low-cost smart antennas for many years, and is currently working on a new concept of AFSS antenna that operates in multi-band multi-beam mode, as shown in Fig. 2.

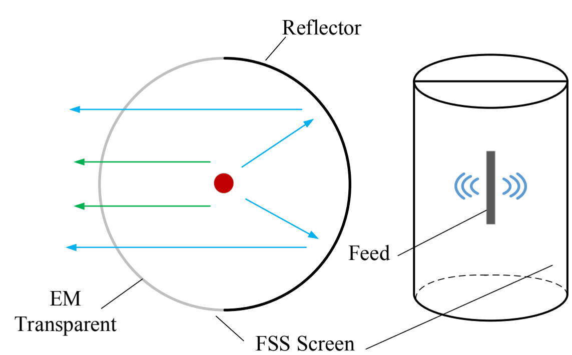

Figure. 1. The operation principle of the AFSS antenna.

Fig. 3 shows some examples of the active microstrip FSSs. Reconfigurability is realized by changing the resonance behavior of the FSS screen by controlling the states of PIN diodes or Varactor diodes. As the Babinet counterpart of the strip FSS, slot type FSS can also be reconfigured using the same technique. Fig. 4 shows three slot-type AFSSs including one dual-band AFSS (Fig. 4 (c)) developed at the research group in the University of Kent.

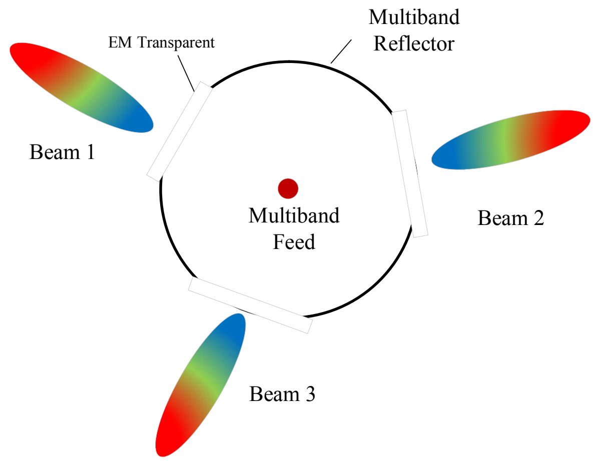

Figure. 2. A new concept of an AFSS antenna operates in multi-band multi-beam mode.

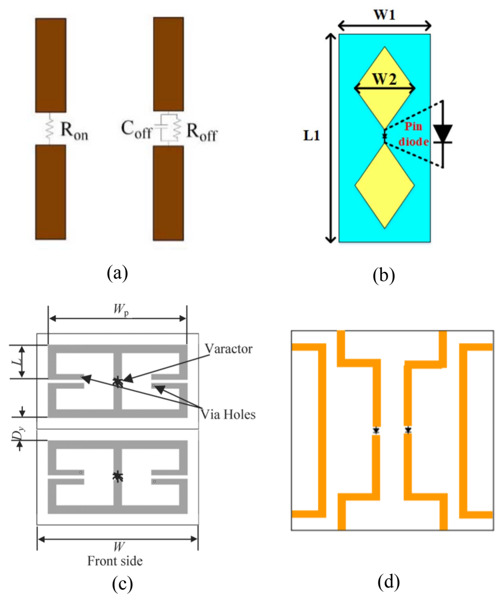

Figure. 3. Some examples of the active FSSs using microstrips. (a) Ref [15]. (b) Ref [17]. (c) Ref [21]. (d) Ref [16].

In theory, half of the radiated waves from the feed would be reflected back by the equivalent reflector. As a result, the gain of the feed would be improved by 3-dB. For this reason, most of the existing AFSS antenna designs have a gain of less than 9 dBi. The gain of the AFSS antenna is improved to 10 dBi through using metallic cones at the top and bottom of the structure [15]. For many applications, it is required to have a more directive beam. In the next section, our on-going work with some preliminary results on the high gain AFSS antenna design will be presented.

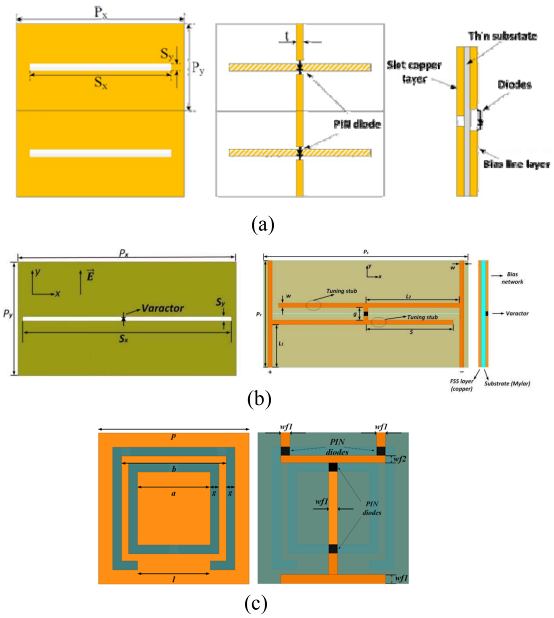

Figure. 4. Some of the slot-type active FSSs developed in the University of Kent. (a) Ref [22]. (b) Ref [18]. (c) Ref [14].

III. HIGH GAIN AFSS ANTENNA DESIGN

The working principle of the high-gain design is to make the AFSS antenna operates in a different mode other than the feed with reflector. Fig. 5 shows the concept of the proposed design. As shown, eight AFSS panels are used to form an octagon shape and a printed monopole is placed in the center as the feed antenna. Different from the conventional designs, two copper plates are placed on the top and bottom of the AFSS antenna. In this configuration, the AFSS antenna operates as a wide slot antenna with an octagonal cavity.

Figure. 5. The configuration of the developed high-gain AFSS antenna.

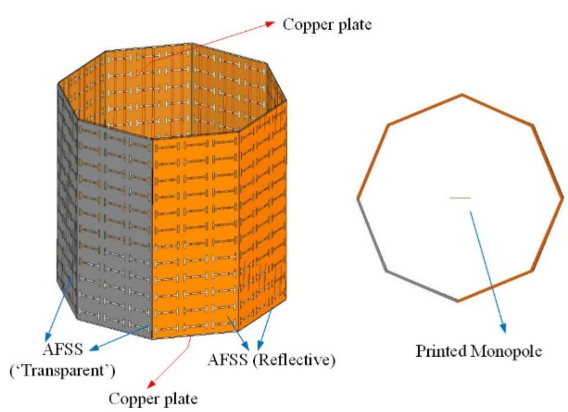

Fig. 6 shows the beam switching performance of the developed AFSS antennas. Because of the symmetrical configuration, only the beam-switching in 0 to 180-degree in the azimuth plane is given. In this design, the diameter of the octagon is chosen to be 165mm with a height of158mm. The antenna is optimized to operate at the central frequency of 3.5 GHz, with 10 dB return loss bandwidth from 3.4 to 3.6 GHz. During the beam switching, two FSS panels are configured to operate in the 'transparent mode' and the rest of the FSS panels are configured as reflectors. The simulation results show that the beams of the antenna can be switched by a step of 45-degree, with a maximum gain of higher than 14 dBi. Compared to the existing designs, the gain of the AFSS antenna is increased by at least 5 dB.

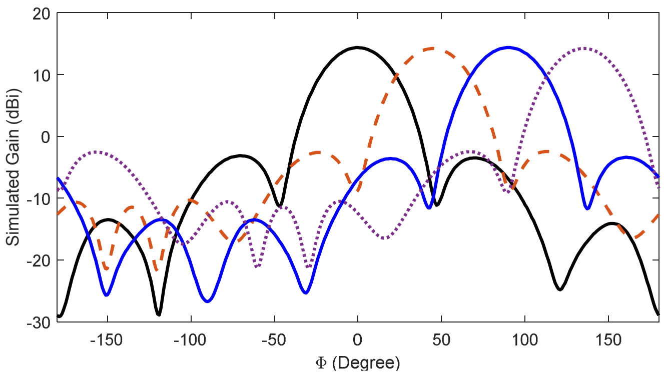

Figure. 6. Simulated beam-switching radiation patterns of the high-gain AFSS antenna at 3.5GHz.

IV. CONCLUSION AND FUTURE WORK

A review of AFSS based low-cost beam-switching antennas including many designs developed at the University of Kent is presented. This type of beam reconfigurable antennas using RF switches or varactors to change the resonant states of the FSS and switch the beam of the antenna in the azimuth plane. Existing AFSS antenna designs show relatively low gain and to overcome this issue, we present our recent research progress at on the high-gain AFSS antenna is presented with some preliminary results.

The future work on the AFSS antenna is to extend its operating frequency to mm-wave and uses MEMS to control the states of the AFSS. In our recent work [20], a 3D coverage beam-scanning AFSS antenna was presented. It is ongoing research to use innovative designs to extend the 3D beam coverage range. Meanwhile, it is important to explore feasible designs to reduce or minimize the number of RF switches, in order to reduce the complexity and insertion loss of the control circuit, as well as reduce the overall cost.

ACKNOWLEDGEMENT

The authors would like to thanks for the funding support from the Engineering and Physical Sciences Research Council (EPSRC) grants EP/N032497/1, EP/P015840/1 and EP/S005625/1.

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