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Design of Active Frequency Selective Surface for Electronically Steerable Antenna

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1. Introduction

During the last decades, an increasing demand of wireless network and cell communication system is observed, which motivated the radio engineers to develop beamforming antennas allowing higher system capacity and more efficient spectrum utilization[1,2]. The application of electronically steerable antenna provides a new solution for omni-beam sweeping with less space occupation and lower cost.

Electrically steerable passive array radiator (ESPAR) antennas composed of passive array monopole radiators which are lumped with biased varactors has been introduced to achieve electronically steerable capacity[3]. A smoothly steerable capability in horizontal plane is achieved, cost and power consumption of ESPAR antenna is relatively low, but narrowing down beam width in vertical plane is still a problem. Past few years, a remarkable antenna is proposed, which is composed of an array of discontinuous strips and PIN diodes inserted into their discontinuities and placed cylindrically around an omnidirectional electromagnetically coupled coaxial dipole (ECCD) array[4]. High gain in vertical gain is achieved by this antenna, and a discontinuously steerable capability in horizontal plane characterized it a sectional antenna which means smoothly steering could not be achieved. A newly developed electronically steerable radiator and reflector array (ESRRA) antenna composed of an array of band reflective active frequency selective has an ability of continuously sweeping in horizontal plane and high gain in vertical plane.

ESRRA antenna in this work is composed of an array of band reflective AFSS units mounted with varactors and it is placed cylindrically around a coaxial colinear (COCO) antenna. The steerable ability in horizontal plane is achieved by the surrounding AFSS array. To make the antenna better performance, the band reflective array should has high reflectivity in reflection band; low returning loss in transmission band, the transmission band should be wider than the communication channel and the tuning range should be wider than the communication band.

In this work we illustrated the concept of ESRRA antenna and analysed design principals of AFSS. Following the principles a novel AFSS with magnetic trap loop structure is developed and tested. The AFSS array is cut into sheets and used building a prototype of ESRRA antenna. The testing results are presented.

2. Structure of ESRRA Antenna

To obtain a reconfigurable radiation pattern the AFSS sheets of units are divided into two semi–cylinders, one reflective, the other passed through. In this work 10 sheets are employed, so the cylinder is divided by means of 5-5 and 4-6. By this mean of converting omnidirectional radiation, 20 sets of configuration are achieved with a sweeping step of 18°. Furthermore by biasing one sheet into half-pass status a set of 4-1-5 is made, such a fine tuning between each 18° is achieved. In this work the ESRRA antenna was composed of ten unit cell sheets surrounding a COCO antenna. A bracket made of nylon stick and Fr4 board is designed to keep the structure. The Fr4 circular has a thickness of 1.00 mm and was carved by a LPKF Protomat S62 to make it accurate. As introduced, ten sheets were made surrounding a COCO antenna, formed a cylinder with a radius of 50 mm. Each sheet is made of seventeen unit cells vertically repeated with a total length of 289 mm, and a width of 29 mm. At the bottom of each sheet a pair wire with a connector is welded to provide reverse voltage for the varactors.

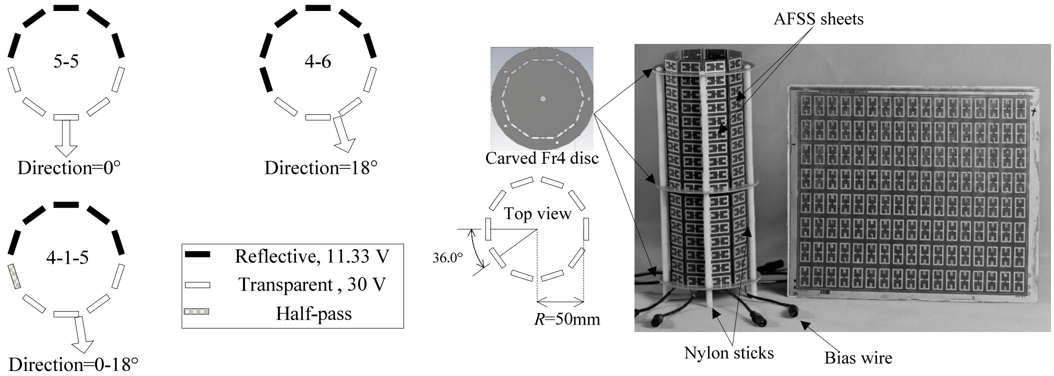


Figure 1: Configuration and Structure of ESRRA Antenna

So far the basic operation method is discussed. Performance of steering is decided by the AFSS sheets, it will be discussed by the following section.

3. Design and Analysis of AFSS

3.1 Principals of AFSS Designing

To convert the radiation pattern using band reflective AFSS units, the unit cells must have the following features. First, low insertion loss is required so that it is transparent to determined waves and high reflectivity, when it works as a reflector. Also the tuning range and reflection bandwidth should maintain the following requirements in Fig. 2.

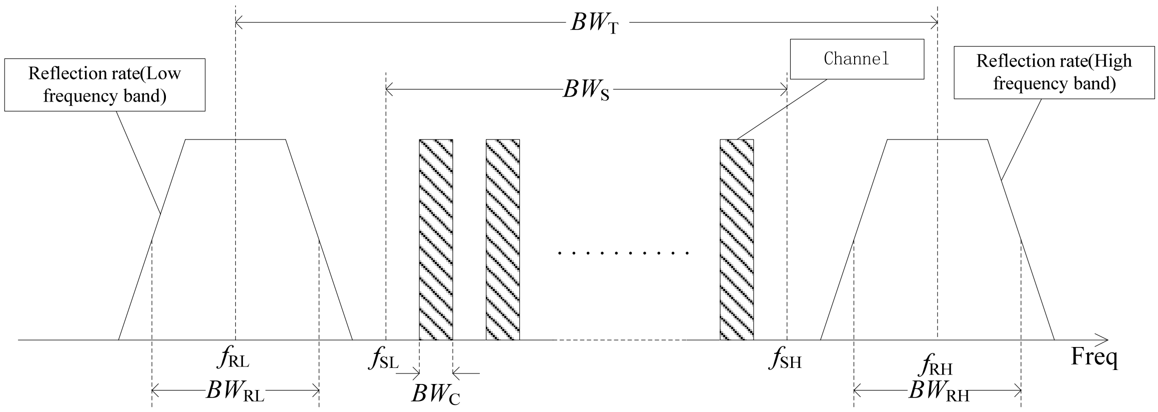


Figure 2: AFSS and System Frequency Spectrum

We can conclude Fig. 2 by following inequalities.

$$BW_T > \frac{BW_{RL}+BW_{RH}}{2} + BW_S \tag{2.1}$$

$$BW_R > BW_C \tag{2.2}$$

$$f_{RL} < f_{SL} - BW_{RL}/2 \tag{2.3}$$

$$f_{RH} > f_{SH} - BW_{RL}/2 \tag{2.4}$$

Here tuning bandwidth range of the AFSS BW_T should be wider than the bandwidth of the certain system by half bandwidth of reflection in low and high frequency (BW_{RL} and BW_{RH}). Also we need the reflection bandwidth BW_R wider than channel bandwidth BW_c all through the system frequency spectrum to keep radiation pattern the same within each single channel spectrum.

3.2 AFSS Unit Structure and Analysis

The structure of AFSS units is illustrated in Fig. 3. The front side of the unit cell is functionality structure, while the back side is biasing network. On each unit cell of the front side, a varactor is located in the middle of the two mirrored parts. W=25 mm L=6.2 mm D=4 mm. In this work, varactor BB857 and high Q inductor LQW15AN22NG00D (made by Murata) are employed. Substrate is made of Teflon woven glass formulated Wangling F4BMX-2 with a permittivity of 3.5 with loss tangent of 0.0007 and thickness of 0.8 mm.

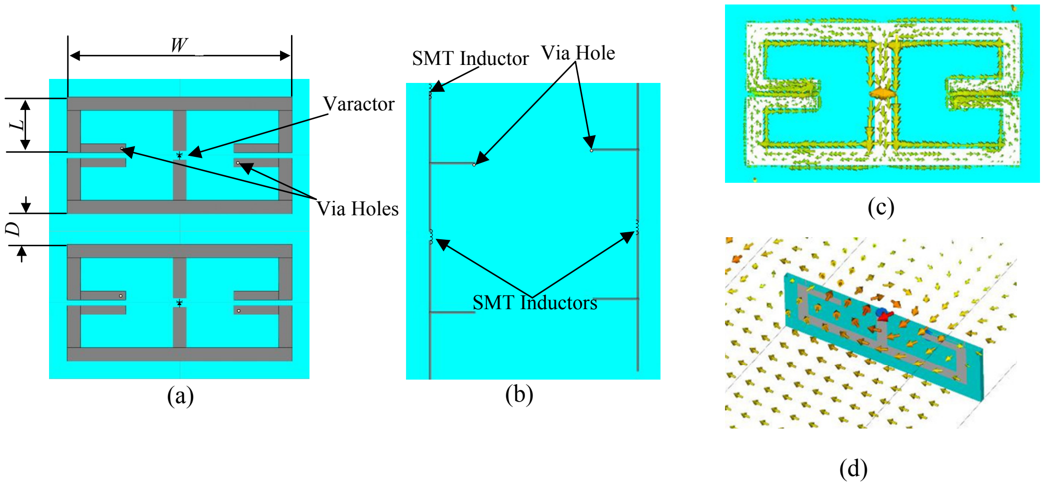
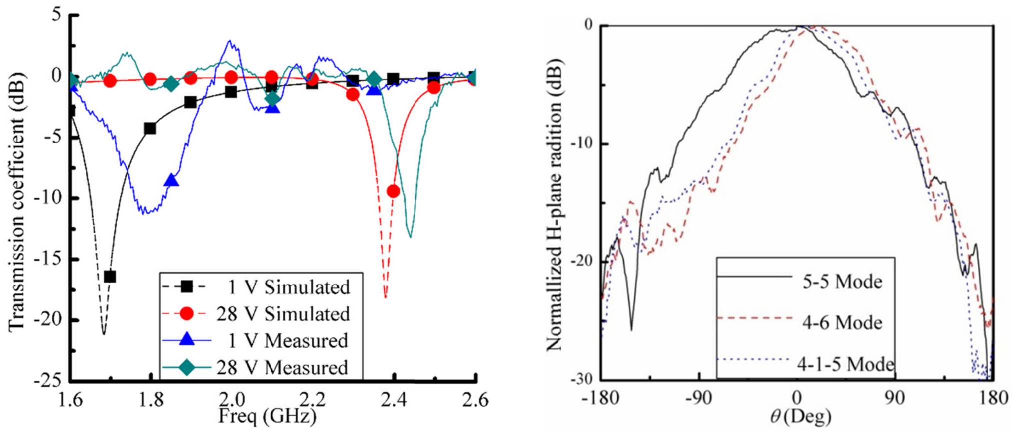


Figure 3: Schematic of AFSS Unit Cells and Magnetic Loop Trap Mechanism (a) Top View (b) Bottom View (c) Surface Current Distribution (d) Magnetic Field Distribution

Full-wave simulation is carried out to study the mechanism of the design by using CST. At resonant frequency, the surface current flow along the inner edge of the metallic patch, most of it passing through the varactor and almost horizontally symmetric. If we consider the patch pattern as two circles placed vertically, the surface current in the two circles go difference clock direction. Responding to the surface current, the magnetic field formed a loop around the central of the patch in horizontal plane. The loop storages EM energy and stops plane wave passing through. Also, because most of the surface current would pass through the varactor, tuning the varactor contributes great for shifting the resonant frequency.

4. Fabrication and Measurement

A prototype AFSS plane is fabricated, and measured in a microwave anechoic chamber. The plane covers the aperture of a wide band horn antenna, which is vertically polarized. Another horn antenna is put more than 5 meters away from the first one at the same altitude, making them pointing to each other with their propagation direction. Bias voltage is manually tuned and certified with a multimeter Fluke B15. After measuring and recording transmission coefficient at different voltage values, the AFSS surface is removed and the transmission coefficient of the two horn antennas is recoded. The difference between the two configurations is the transmission coefficient of the AFSS surface. The results of measurement and simulation are shown in Figure 4， a smooth tuning is achieved. A shielding ability more than 10 dB is obtained from 1.76 GHz to 2.45 GHz which covers several ISM bands.



(a) (b)

Figure 4: Measurement Results (a) AFSS Measurement and Simulation (b) ESRRA Radiation Pattern

Fig. 4 (b) shows the measurement results of the ESRRA antenna. A main lobe of 96° in H-plane at 5-5 mode was formed, which is about 20° wider than it in 4-6 mode and 4-1-5 mode. The measured gain of the antenna is 8.83 dBi for 4-6 mode and 8.54 dBi for 5-5 mode. The bias voltage was tuned manually in this experimental investigation. And in 4-1-5 mode the voltage of half-pass is 8.63 V. Front-to-back ratio in the directivity pattern is more than 20 dB with the depth of null point below -30 dB.

5. Conclusions

In this paper we propose a high performance AFSS for ESRRA antenna. Designing principals of AFSS is discussed and given by inequalities. A wide tunable range is achieved by employing magnetic loop trap structure, which is simulated and discussed. The prototype antenna is fabricated and experimentally investigated. The front-to-back ratio in the directivity pattern is about 20 dB with the depth of null point at 34 dB and the gain of the system is 8.83 dBi. The proposed antenna has shown the ability as an omnidirectional antenna with a smoothly reconfigurable feature in the H-plane, and high gain in E-plane. At the same time the power consumption is less than 1.02 mW.

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