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Tuning technique for active FSS arrays

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A novel biasing technique is described for active frequency selective slot arrays. The bandpass response can be switched between transmitting and reflecting modes, or tuned over a predetermined frequency range using two different biasing circuit configurations based on the same technology. The biasing layer is separated from the slot layer by a very thin, flexible, substrate while pin and varactor diodes are employed for switching and tuning, respectively. One application is the time-dependent modification of the EM architecture of buildings, permitting access to frequency bands as desired.

Introduction:

There is increasing research interest in employing frequency selective surfaces (FSS) to modify radio propagation in the built environment [1, 2]. As most of the mobile and wireless technologies used indoors work between about 300 MHz and 6 GHz, the FSS designed for this application needs to operate in a very wide frequency band [2]. Active frequency selective surfaces can add a higher level of control over the electromagnetic wave propagation in buildings. Two related procedures can be considered when applying active devices to frequency selective surfaces: switching and tuning. Switching FSS between transmitting and reflecting modes using pin diodes on metallic dipole patches is well known [3]. The development of switching and tuning on slot FSS, however, has been reported more recently [4, 5]. Bandpass active FSS consisted of slots etched on one side of an FR4 substrate, with the biasing circuit on the other side, and metallic vias connected both.

In this Letter we propose a double-sided structure, sandwiching a very thin, flexible dielectric material. The thin substrate allows the biasing circuit to be placed with the active devices on its rear side without physical connection to the front surface which contains the slots. These in turn could lay on a second, thick dielectric layer if necessary for support, or for additional bandpass shaping. We describe the application of this biasing technique to two well known basic active configurations using singularly-polarised dipole slots. The first is a switchable structure in which the applied biasing circuit uses pin diodes connected in series. In the second, the capacitance of varactor diodes, placed in parallel, is varied by an applied external voltage.

Design and results:

The front and the rear views of the unit cell for the switchable FSS are shown in Figs. 1a and b. A flexible polyester substrate of 0.05 mm thickness with metal cladding on its two sides was used as the substrate in all the designs presented here. The slots comprising the FSS were etched on the front while pin diodes were placed on the biasing circuit at the back. A side view of this novel biasing configuration is illustrated in Fig. 1d. This switched array consisted of 8 ⍰ 3 slots with a rear circuit of three parallel lines with eight diodes in series. The dimensions were: slot length l ¼ 52 mm, width w ¼ 0.2 mm, Px ¼ 54 mm, Py ¼ 25 mm, t ¼ 2 mm. The relative permittivity 1r of the substrate was approximately 3. BAR64-02 silicon pin diodes (with forward resistance rs ¼ 2.1 V and capacitance at 0 V of Cs ¼ 0.17 pF) were employed. The dimensions of the slots were calculated using CST Microwave StudioTM, while the measurements were carried out using two log periodic antennas at

1 m from a 3 × 3 m panel containing the FSS. Fig. 2 shows the measured transmission response of the switching FSS in its OFF and ON states at normal wave incidence angle. In the OFF state, resonance occurs at 2.5 GHz with a 210 dB fractional bandwidth of 75% and insertion loss of about 1 dB. The transmission coefficient drops to 16 dB when the diodes are switched ON, a 15 dB power difference from the OFF state. The ON/OFF relative power ranged between 14 and 15 dB across the 2.4 to 2.5 GHz Bluetooth band. At TE458 incidence, the resonant frequency did not vary significantly, but the insertion loss increased to 1.5 dB when the diodes were OFF. At TM458, the insertion loss was again 1.5 dB, while the power difference between the ON and OFF states decreased to 10 dB.

Tuning was achieved using a parallel circuit configuration, with the two lines of the DC voltage parallel to every single slot in a row, as shown in Fig. 1c. (A circuit with all slots in a column, fed simultaneously would also be possible.) The FSS itself consisted of an 8 × 4 array of dipole slots on a rectangular lattice with dimensions: l ¼ 46 mm, w ¼ 0.2 mm, Px ¼ 48 mm, Py ¼ 25 mm. The width of the strips providing the bias at the rear was d ¼ 2 mm. BB857 silicon varactor diodes with a tunable capacitance range from 0.5 pF (28 V) to 7.2 pF (1 V) were chosen.

The measured transmission response of the tunable FSS for 5, 10, 15, 20 and 28 V across the varactors is shown in Fig. 3. The resonance frequency increased from 1.3 GHz for 5 V to 2.2 GHz for 28 V, while the passband insertion loss decreased from 6.4 to 2 dB. The 210 dB fractional bandwidth also increased from 15 to 43%. Table 1 shows the resonant frequency, insertion loss and bandwidth for all the different voltage values studied. The FSS is able to tune across the frequency range containing the DCS1800, DECT, UMTS and the Bluetooth bands. Out of band, the signal isolation is modest, but in mobile communications, especially in the built environment, an improvement in the carrier-to-interference ratio of only about 15 dB has been demonstrated to give a reduction by about 30 in the outage probability [6].

Conclusions:

A novel biasing technique has been described for active frequency selective slot arrays with diodes capacitively coupled via a very thin, flexible substrate. Switched and tuned dipole versions using this technology have been demonstrated. The main aim is to dynamically control the propagation of electromagnetic waves in buildings, although the active FSS could also be applied to other antenna applications such as beam steering and electromagnetic bandgap structures. A more detail study of the FSS together with configurations for loop and cross elements will be presented elsewhere. An application to beam steering is also being investigated as part of the research work. A patent describing this FSS has been filed as 'Tunable Surface', application no. GB 0902389.6.

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Table 1: Performance of tunable FSS for various diode bias voltages

Voltage (V)	Frequency (GHz)	− 10 dB bandwidth (%)	Insertion loss (dB)
5	1.31	15	6.4
10	1.72	24	3.3
15	1.97	27	2.8
20	2.10	35	2.1
28	2.22	43	2.0

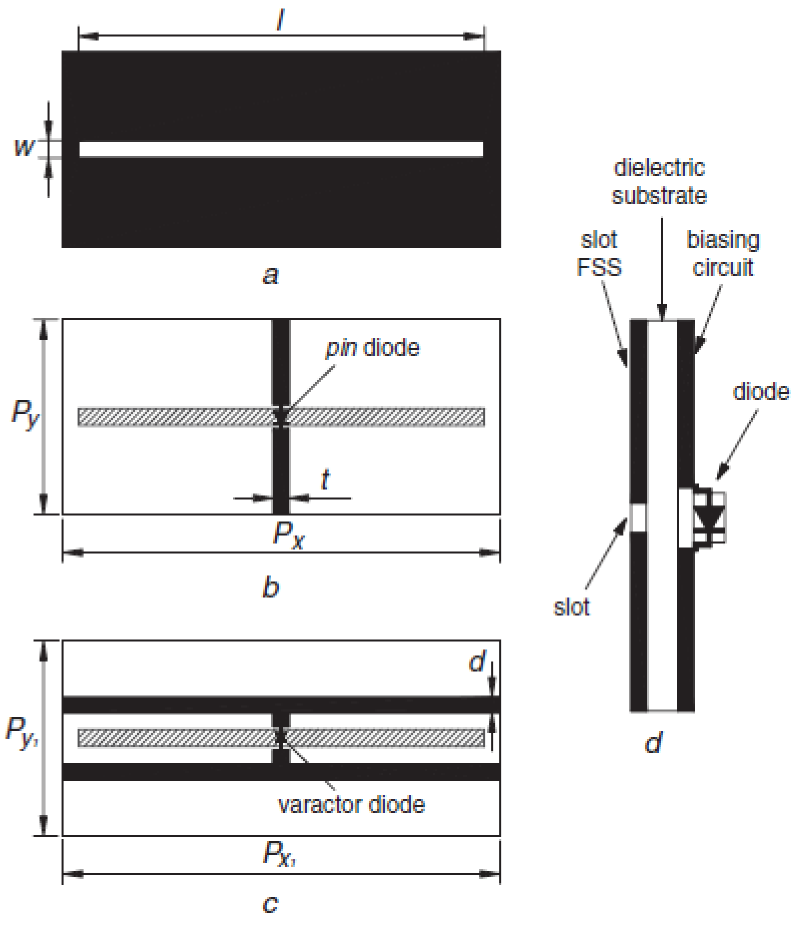

Fig. 1 *Unit cell of active frequency selective slot array*

a Front view with slot
b Rear view of switchable FSS
c Rear view of tunable FSS
d Side view of novel biasing configuration

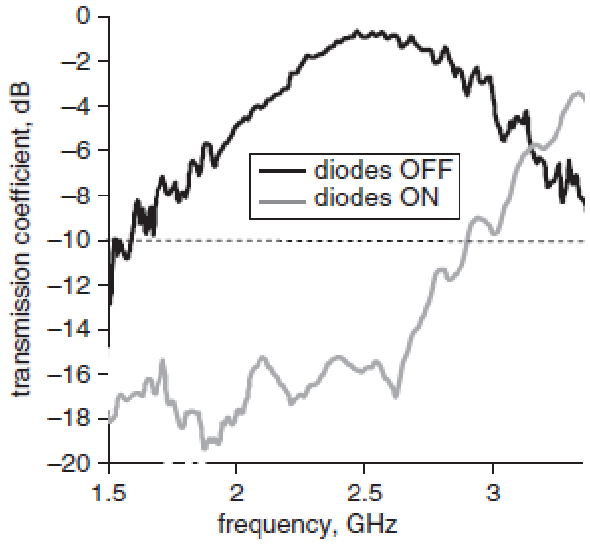

Fig. 2 *Transmission response of switching configuration at normal wave incidence*

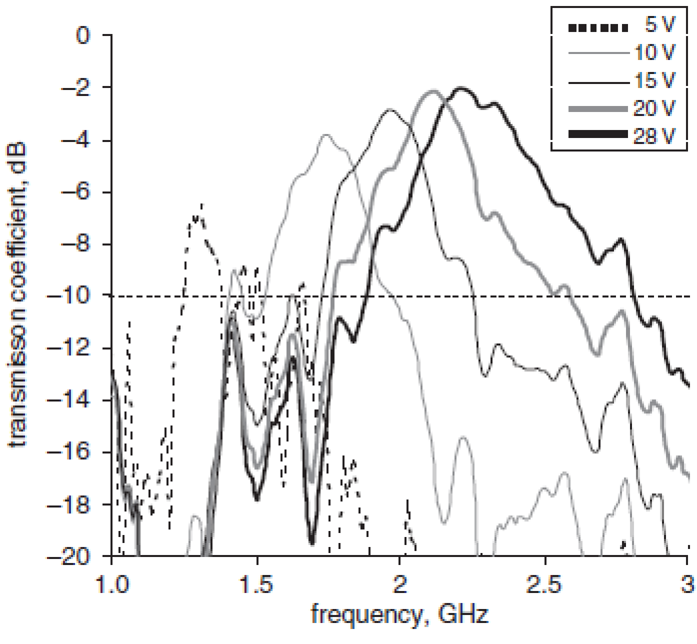

Fig. 3 *Transmission response of tunable FSS at normal incidence*