Frequency reconfigurable patch antenna array

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A frequency reconfigurable antenna array is introduced. The array consists of planar radiating elements that may be interconnected through computer-controlled switches to form larger elements radiating at frequencies lower than the resonant frequency of the individual elements. Simulations using a 2 × 2 array of patch antennas connected using either hard shorts or RF shorts are used to establish the viability of the concept. The simulated arrays were fabricated, the measured properties of the arrays being in good agreement with predicted results. Both of the shorting methods resulted in reduction of the resonance frequency to half that of an individual element, while the radiation pattern of the individual element was maintained.

Introduction: There is great interest in making antennas that operate in more than one frequency band. Consumer electronics devices, driven by a need to satisfy the operating requirements of services that span several operating bands, may be cluttered with antennas. Some microstrip antennas are able to cover more than one frequency band without the need for active tuning using switches or other techniques [1, 2]. In contrast, reconfigurable antennas use switching components such as *pin* diodes, varactor diodes, and micro-electromechanical systems (MEMS) to provide multi-band operation [3–6]. Although these approaches are promising, significant drawbacks, such as the complicated networks required to maintain a good match, reduce their appeal. In addition, many reconfigurable antennas employ a large number of switches that often require complicated biasing networks, making them difficult and costly to implement in large arrays.

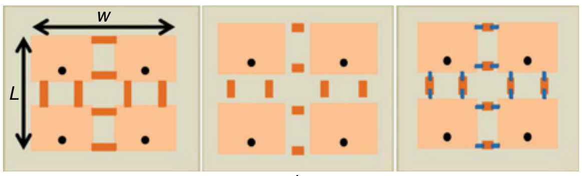

Fig. 1 *Designs for connected patch antenna arrays. Hard shorts formed by copper strips (Fig. 1a); unconnected array (Fig. 1b); RF shorts formed using capacitors (Fig. 1c)*

Black dots show feed positions

A practical alternative to create reconfigurable antennas is to focus on making the entire array reconfigurable without altering the individual elements. This Letter proposes electrically connecting radiating elements together to make an array to operate at a lower frequency, thereby being the first attempt, to the authors' knowledge, of making an array frequency reconfigurable without changing any antenna elements themselves. If a large array operates at a given frequency, connections can be added between subsets of the elements to create a new array, although with a smaller number of elements, that operates at a lower frequency. As a simple example, the patches in a 2 × 2 microstrip patch antenna array may be connected together to create a single effective patch that resonates at a lower frequency that is proportional to the overall edge length. In this Letter, the performance of such an array is investigated to demonstrate the concept of array reconfigurability as a means for multi-band tuning. We show through simulation and experiment that an array that in its unconnected state exhibits normal array behaviour at its nominal operating frequency can be reconfigured through interconnects between patches to operate as a single patch at a lower frequency. The ratio between the two operating frequency bands is 2.5:1 and the concept is scalable and could be used at any frequency.

Proposed solution and design: Fig. 1 shows three array structures. In Fig. 1*a*, individual patch elements are connected by hard shorts consisting of copper strips patterned on the front side of the dielectric substrate. In Fig. 1*b*, smaller copper strips are placed between the patches but left unconnected. In Fig. 1*c*, gaps are bridged using capacitors to create RF shorts. Both the hard shorts and RF shorts allow current to flow between the elements, creating a new structure with a lower resonant frequency.

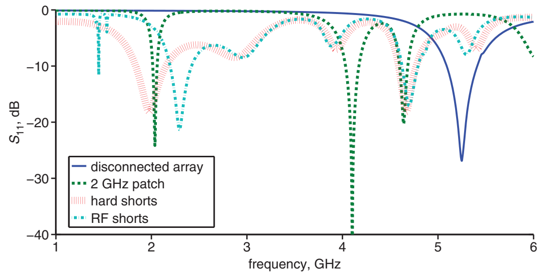

Fig. 2 *Simulated reflection coefficients for various array configurations*

The array elements have conventional $\lambda_o/2$ spacing. Although decreasing the separation between the patches could improve performance in the connected state, mutual coupling is increased and decreases the disconnected state performance. Further investigation is needed to better understand this trade off and determine an optimal spacing. No significant effects from mutual coupling were seen using conventional spacing.

The RF shorts are a model for the switches that would be used in the proposed implementation. The most straightforward way to implement actual switches and their biasing networks into this design to produce discrete connected and disconnected states is to feed the ports of the individual elements with biasing tees that have alternating polarity with MEMs or varactor diodes replacing the capacitors. Having individually controlled switches could also add greater flexibility to the arrangement.

The placement and dimensions of the shorting strips were determined through trial and error. To get enough current flow between patches two connecting strips were used. Various values of capacitance were simulated to explore the effect of switch capacitance on the radiation performance of the connected array. The capacitance value is critical to achieve a low impedance path for current travelling between radiating elements. The losses from the capacitors and switches were not included in the simulated models. Good results with reflection coefficients of >15 dB were found for each of the capacitances tested. A capacitance value of 3 pF was chosen to use with the fabricated prototype array, since this value is in the typical range of modern MEMS switch technology and showed good radiation performance.

The substrate had a total width of 68 mm and length of 68 mm for the 2 × 2 arrays and a width of 36 mm and length of 36 mm for the single patch. A single patch element is designed for a resonant frequency of 5 GHz and has dimensions of 18 × 18 mm. The 2 × 2 arrays have a total width (W) of 50 mm and a total length (L) of 50 mm as indicated in Fig. 1. A single patch antenna with the same dimensions has a resonant frequency of around 2 GHz. The connecting strips are 5.6 mm wide and 1 mm gaps are left for placement of the capacitors on the structure with RF shorts as well as to act as gaps to electrically disconnect the patches in the unconnected configuration. The coaxial cable feeds are positioned to be matched with a 50 Ω cable through a SMA connector attached through the ground plane. The connectors are centred along the width of the patches but sit in about one-fourth of the length of the patches. The feed point placement was optimised for the disconnected state and further work is needed to determine how well it scales in connected states. All of the elements are fed in phase.

Simulation results: Simulations were performed using ANSYS HFSS®. The results for a 2 × 2 array with hard shorts (HS) between patches, with RF shorts between patches, and with the patches unconnected are compared in Fig. 2 and in the top row of Fig. 3. The results are also compared with those of a 50 Ω patch that has the same dimensions as the connected array and which resonates at 2 GHz.

It can be seen that the array with gaps in the connecting lines acts like an ordinary 2 × 2 array given its resonance around 5 GHz and greater total gain. This demonstrates that when the electrical connection between the patches is removed the patches perform like a normal array. The two configurations with connected elements display a resonance at a lower frequency of around 2 GHz, and show a gain at that lower frequency similar to that of a single patch antenna. In Fig. 2 and in the first row of Fig. 3 it can be seen that the electrically connected arrays have a resonance around 2 GHz and radiation patterns very similar to the 2 GHz patch. The ratios of resonance frequencies (FR) vary given the method used to connect the patches, the FR for the hard shorted array being about 2.66:1 and the FR for the RF shorted array around 2.29:1.

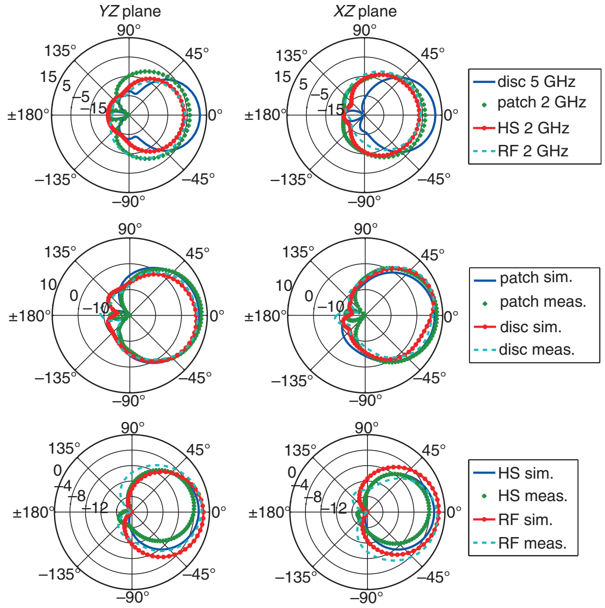

Fig. 3 *Simulated and measured radiation patterns (dBi)*

All patterns are taken at the device's resonant frequency (as indicated in legend). The top row contains results for arrays when all four ports were fed, while the middle and bottom rows show results when only one port is fed

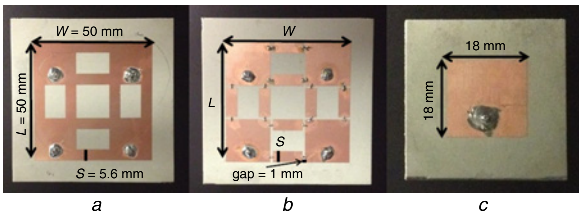

Fig. 4 *Fabricated 2 × 2 array with hard shorts (Fig. 4a); fabricated 2 × 2 array with capacitors added for RF shorts (Fig. 4b), unit measured for disconnected array same as shown here except with no capacitors present; single reference 5 GHz patch antenna (Fig. 4c)*

Fabrication and measurements: The antennas were fabricated using conventional photolithography on a Rogers RO5880 substrate 2.54 mm thick, with a dielectric constant of 2.2 and a loss tangent of 0.0009. Four units were fabricated: a single patch antenna designed to operate at 5 GHz, a 2 × 2 array of 5 GHz patch antennas with shorting strips but with a 1 mm gap between the patches and the strips, a 2 × 2 array of 5 GHz patch antennas with connected shorting strips, and a 2 × 2 array of 5 GHz patch antennas with shorting strips, and 3 pF capacitors across a 1 mm gap between the patches and the strips to act as RF shorts (see Fig. 4). Conventionally, the performance of arrays is measured by using a power splitter to feed each element. However, since the arrays described here are electrically connected to form a single element, having variations in phase from the four ports can greatly affect the measured performance. For simplicity, all array measurements were made with three of the four ports terminated by matched loads. To allow for comparison, the simulations were repeated with matched loads at these ports. The reflection coefficients were measured using an Agilent N5227A network analyser and the radiation patterns were measured using a SATIMO Starlab® near-field measurement system.

All four fabricated antennas were measured and the results are shown in Figs. 5 and 6 and in the middle and last rows of Fig. 3. It can be seen that the radiation patterns were maintained although the gain observed is less than with all the four ports fed, and that the connected arrays have a reflection coefficient similar to the single 2 GHz patch in Fig. 2. The measured reflection coefficients for the disconnected array and for the single patch are not quite as good as predicted, this is likely due to additional losses from the real SMA connectors and the solder which affects the impedance match between the measuring cable and the device under test. It is seen in Fig. 6 that the FR of the measured arrays is about 2.66:1 for the hard shorted array and 2.5:1 for the RF shorted array. These values match closely with what was predicted by simulation. We predict that similar reductions in frequency will occur upon shorting the patches when all four ports are fed in phase.

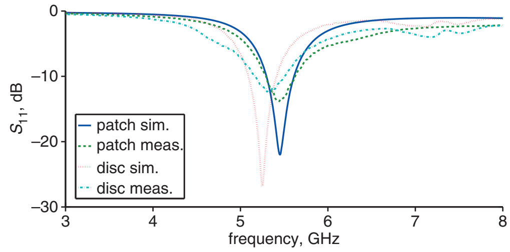

Fig. 5 *Reflection coefficients for single patch antenna and for disconnected array while three ports are terminated with matched load*

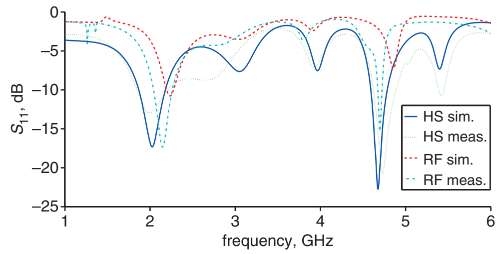

Fig. 6 *Reflection coefficients for connected arrays while three ports are terminated with matched load*

Conclusion: A method for tuning an antenna array by connecting elements together rather than by altering the elements themselves is introduced. Simulation compares well with measurements of fabricated units when the arrays are fed at one port while the other ports are terminated, showing that the resonance frequency can be reduced by a factor of ~2.5. By using capacitive RF shorts, the feasibility of the method is demonstrated for tuning an array with computer-controlled MEMS switches. Such a configuration also allows the active control of polarisation of the radiated field. The possible implementations of arrays with actual switched elements are currently under study.

Submitted: *22 May 2015* E-first: *22 September 2015*
doi: 10.1049/el.2015.1771
One or more of the Figures in this Letter are available in colour online.

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