Short Communication

# A low profile reconfigurable antenna for defense aircrafts

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**Abstract**

In this paper a low profile frequency reconfigurable antenna is proposed that can conform to the host surface. The proposed design is a pixelated antenna structure with a grid of small metallic patches with RF switches for re-configurability. The prototype of the proposed design is designed on an FR4 substrate with the relative dielectric constant of 4.4 and thickness of 1.6 mm. This antenna is capable of resonating in three different frequencies. The prototype resonates at 10 GHz with return loss of − 12.47 dB and gain of 4.35 dB, 3.9 GHz with return loss of − 19.95 dB and gain of 3.52 dB and 2.6 GHz with a return loss of − 14.22 dB and gain of 4.26 dB. The simulated result shows that the gain of the pixel antenna on FR4 substrate ~ 4 dB comparable to gain attained by pixel antenna on substrates with low tangent loss and low dielectric constant. It is observed that the measured results are in good agreement with the simulated result.

**Keywords** Conformal · Reconfigurable · Pixel patch component

## 1 Introduction

Micro-strip antenna patches are placed above what may be characterized as a conducting plane with a dielectric substrate separating the patch from the conducting plane. The proposed antenna can be made conformal to the surface of the aircraft. Micro-strip antenna technology is the most suited for conformal antennas.

The pixelated structure of the antenna makes it capable of beam steering, beam shaping, operating at multiple frequencies and multiple polarizations. It is configured, reconfigured, tuned and steered as per the requirement. It can be made reconfigurable by connecting the adjacent pixels by RF switches. MEMS switches could be integrated with the pixels to achieve a reconfigurable aperture [1].

In defence aircrafts for communication, one or more high gain satellite communication antennas are required. Conventionally used steerable high gain dish antennas are bulky/heavy and requires large holes on the pressurized aircraft hull and a high profile radome that creates an aerodynamic drag and thus increases fuel consumption. The proposed antenna structure with MEMS switches could be integrated on the aircraft surface especially belly or the radome and avoid extra drag. Thus, the proposed design can be used for defence fighter aircraft that require an antenna to conform on its surface due to structural, aerodynamic, and space limitation (Fig. 1).

Pixel patch antennas are one of the most promising antenna architectures for the next generation of reconfigurable antenna [2]. It consists of a grid of electrically small metallic patches where each pair of adjacent patches is interconnected by RF MEMS switch [3].

Pixel antennas provide a new level of re-configurability due to the huge flexibility of their switches pixel patch surface which provides simultaneously tenability of impedance and radiation parameters covering wide frequency ranges, steering the beam over large angular ranges and switching between multiple polarizations [4].

The proposed design is a frequency reconfigurable antenna on FR4 substrate. In [5] a frequency reconfigurable antenna on a RT Duroid substrate is simulated and discussed. Re-configurability can be achieved by

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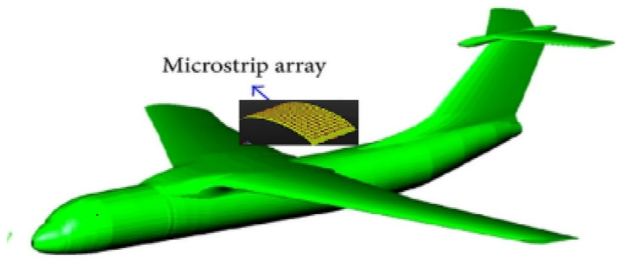



**Fig. 1** Proposed antenna conformal on the aircraft surface

controlling the effective length of the antenna. This effective length can be changed by adding or removing a part of the length by using switches.

RF MEMS switches are used for reconfiguration. MEMS switches offer greater advantages such as small insertion loss, less energy consumption, excellent quality factor (Q), RF isolation and less expensive [6, 7]. The activation or de-activation of these switches modifies the current distribution over the antenna surface therefore providing reconfiguration capability to the antenna structure. This structure reshaping capability is what allows pixel antennas to achieve a high degree of re-configurability over frequency, radiation pattern and polarization.

The designs of RF MEMS switches depend on their usage as series or shunt, movement could be lateral or vertical, it could have metal-to-metal connection or capacitive connection and actuation could be electrostatic, magnetostatic, piezoelectric or thermal [8]. In [9] a fixed–fixed metal membrane RF MEMS series switch is proposed for integration with a reconfigurable antenna.

The software used to model and simulate is Ansoft HFSS. It is a Finite Element Method solver for electromagnetic structures. It includes a linear circuit simulator with integrated optimetrics for input and matching network design. HFSS solver incorporates a powerful, automated solution process. In the software the geometry, material properties and the desired output are specified.

The software automatically generates an appropriate, efficient and accurate mesh for solving the problem using the selected solution technology.

## 2 Proposed design

### 2.1 Design

#### 2.1.1 Single patch antenna design

A single patch antenna is designed for a frequency of 10 GHz on the FR4 substrate with a height of 1.6 mm.

The design equations/formulae of the single patch antenna for a frequency of 2.5 GHz are as shown below: [9–11].

Width of the patch is given by

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Due to the fringing effect, the effective dielectric constant is calculated as follows:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-\frac{1}{2}} \tag{2}$$

Effective Length due the fringing effect is given by

$$L_{eff} = \frac{c}{2\sqrt{\varepsilon_{reff}}}\left(\frac{1}{f_r}\right) \tag{3}$$

Length Extension

$$\Delta L = 0.412h\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\right)\left(\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right) \tag{4}$$

Physical Length of the patch

$$L = L_{eff} - 2\Delta L \tag{5}$$

Theoretical Calculation using the above equations.
The following solution is obtained:
Width of the patch: 7.3 mm
Length of the patch: 6.5 mm
Probe position: 1.25 mm offset from the centre.

#### 2.1.2 Frequency reconfigurable antenna design

Figure 2 shows the schematic of a 3 × 3 array reconfigurable antenna. In this design the patches are connected to the adjacent patches using micro-strip lines along the non-radiating edges. The pixels are connected to the adjacent patch along the radiating edge using switches. In the simulations the adjacent pixels are connected using the conducting strips. The ON switch condition is specified by the connecting strip and the OFF switch condition by the removal of the conducting strip [6].

The substrate is FR4 glass epoxy with the dielectric constant of 4.4 and a thickness of 1.6 mm. The patches are of copper. The microstrip lines joining the patches are also of copper. The adjacent patches along the radiating edge are connected with the switches. Thus in this proposed design six switches are required. The switches connecting the adjacent row of patches are turned ON at the same time as well as should have less switching time. In this proposed design there are thus two rows of

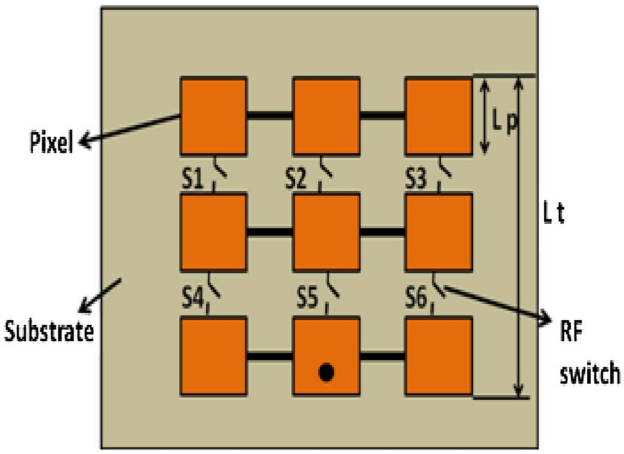



**Fig. 2** Schematic diagram of a 3 × 3 frequency reconfigurable patch array antenna

switches. The lowest of the patches are coaxially fed. The subsequent patches are kept disconnected. When the first row of switches (S4, S5, S6) are turned ON the two adjacent row of patches are connected together and gives a resonant frequency.

When the next row of switches (S1, S2, S3) are also turned ON with the first row of switches still ON the patch structure resonates at a third lower frequency.

## 3 Modelling and simulation in HFSS software

The designs of the three configuration are modeled and simulated in HFSS software. The adjacent rows are connected using conducting strip for an ON switch and no connection for an OFF switch, as shown in Fig. 3.

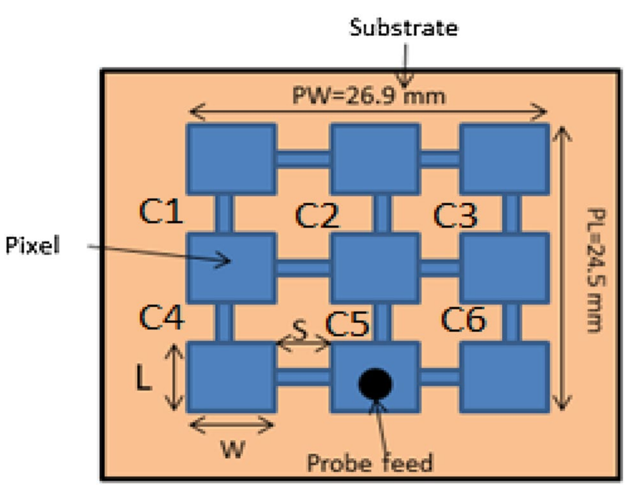


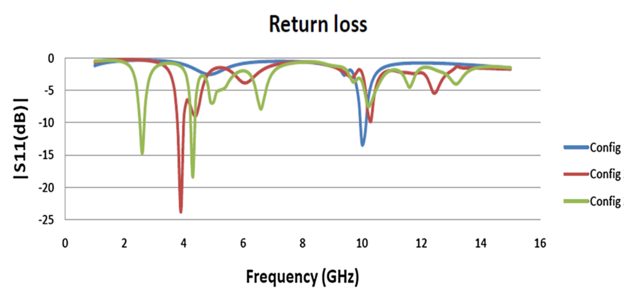

**Fig. 3** Pixel antenna with connection tabs

i. Configuration 1: When no connection between the adjacent rows, all connection tabs removed.
ii. Configuration 2: When two rows are connected using connection tab C4, C5 and C6.
iii. Configuration 3: When all connection tabs are connected C1–C6.

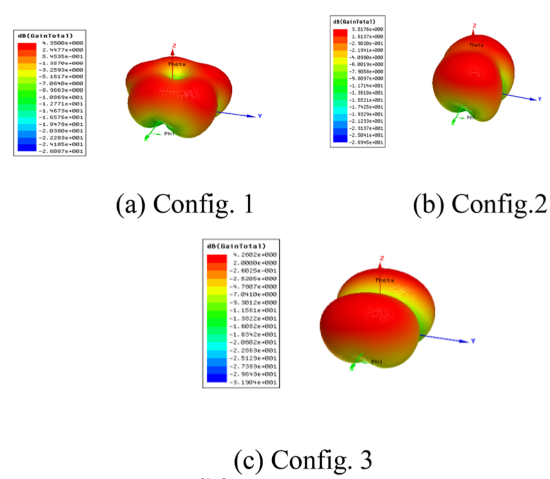
## 4 Simulation results

### 4.1 Simulation results of different configurations

Figure 4a shows that the design resonates at three different frequencies depending on the number of rows of the pixels connected. When all the connection tabs are connected it resonates at a frequency of 2.6 GHz with a return loss of – 14.22 dB, when two rows are connected with tabs C4, C5, C6 ON, it resonates at a frequency of 3.9 GHz with a return loss of – 23.80 dB and when all the tabs are removed, it resonates at a frequency of 10 GHz with a return loss of – 13.35 dB.




**(a)** Simulation result of the three configurations




**(b)** Radiation Pattern

**Fig. 4** **a** Simulation result of the three configurations. **b** Radiation Pattern

Figure 4b shows the radiation pattern with a gain of 4.26 dB for Configuration 1, 3.52 dB for configuration 2 and 4.35 dB for configuration 3. This result is comparable to the gain of 5 dB attained with RO 4003 (Ɛ r = 3.55, tan δ = 0.002) substrate reported in [3].

## 5 Fabrication results

The antenna prototypes of the three configurations are fabricated as shown in the Fig. 5. The three configurations were fabricated on the FR4 substrate with connections between the adjacent rows. The ON switch was fabricated with the copper strip between the adjacent rows and an OFF switch with no connection (Table 1).

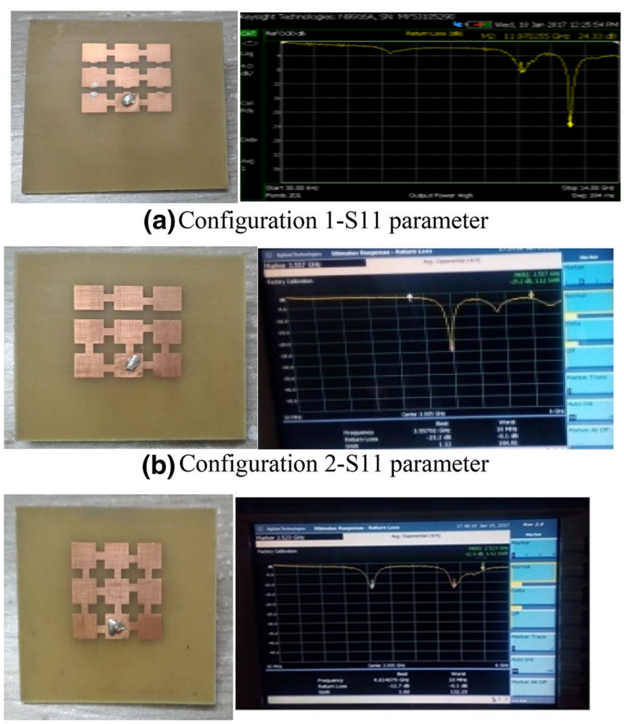



**Fig. 5** Fabricated prototype of pixel antenna configurations

## 6 RF MEMS switch design

The RF MEMS switch for Integration with the pixel antenna is a fixed–fixed metal membrane series switch as discussed in [9]. The structure of the RF MEMS switch is as shown in Fig. 6.

The design discussed in [9] is analyzed using the HFSS software.

When the actuation voltage is applied the metal membrane is pulled down shorting the gap in the transmission line. It has high impedance when in un-actuated state due to the air gap between the membrane and bottom electrode. When the membrane is pulled down it has a low impedance and high capacitance. A dielectric is deposited on the bottom electrode to avoid a short. A dielectric layer is overlaid above the RF line to avoid an interference of the DC bias voltage and the RF signal [12–14].

The switch design proposed in [9] is simulated in HFSS as shown in Fig. 7.

The simulated results are shown in Fig. 8. This includes the Return loss when switch is ON, Insertion loss when switch is ON and isolation when switch is OFF.

### 6.1 Simulation result of the RF MEMS switch in HFSS

The Simulation result shows that Return loss at 12 GHz is − 16.90 dB, Insertion Loss when switch is ON is − 0.3730 dB and Isolation is − 30.81 dB.

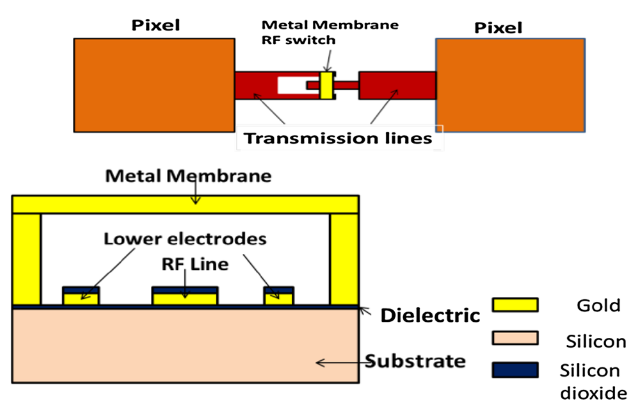



**Fig. 6** Schematic diagram of fixed–fixed metal membrane RF MEMS switch integrated with the pixels

**Table 1** Fabricated and simulated result

| Connection tabs | Config. | Simulated result | | | Measured | |
|---|---|---|---|---|---|---|
| | | Freq (GHz) | Return loss (dB) | Gain (dB) | Freq (GHz) | Return loss (dB) |
| NIL | 3 | 10 | − 12.47 | 4.26 | 9.8 | − 9.89 |
| C3, C4, C5 | 2 | 3.9 | − 19.95 | 3.52 | 3.56 | − 25.2 |
| C1, C2, C3, C4, C5, C6 | 1 | 2.6 | − 14.22 | 4.35 | 2.52 | − 12.6 |

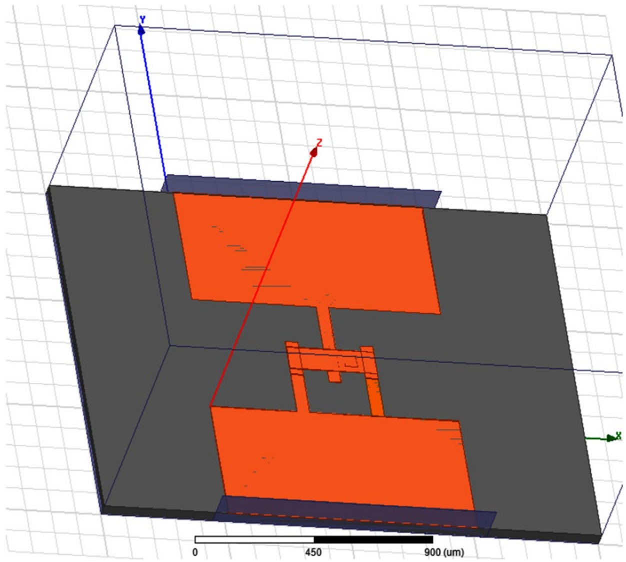



**Fig. 7** Model of the RF MEMS switch in HFSS

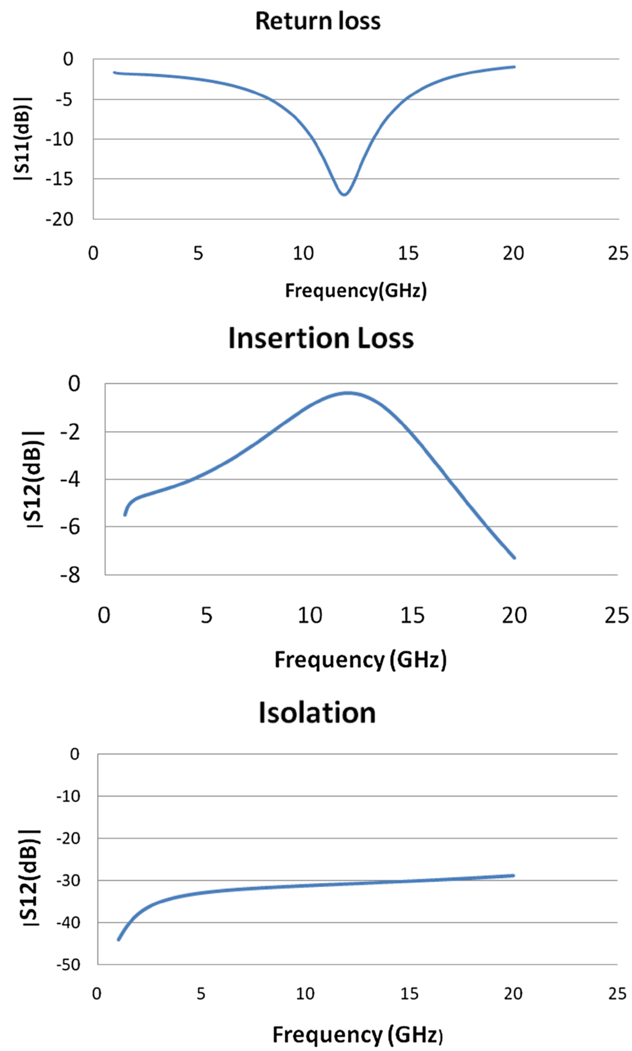



**Fig. 8** Simulation result for return loss, isolation and insertion loss of the RF MEMS switch in HFSS

## 7 Conclusion

In this paper, a frequency reconfigurable pixel patch antenna is proposed that can be made conformal to the host surface and can be easily integrated with other MICs on the same substrate. Thus these antennas can be embedded on the body of the aircraft.

The proposed concept of frequency reconfigurable antenna can replace the bulky antennas by a single reconfigurable antenna. This proposed reconfigurable antenna can be embedded on the body of the aircraft. This will reduce space, weight, drag and improve antenna performance.

The proposed design is an antenna structure with reconfigurability. This proposed design could be directly applicable to the satellite communication or the moving ground vehicles. The ability to electrically steer the antenna beam and vary its operating frequency allows antenna to be tracked from the ground vehicles moving on rough roads as well as aircraft maneuvering in flight. Most military aircraft and many military vehicles can use this rapidly reconfigurable, low profile SOTM capability.

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## Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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