Comparison between a Novel Liquid Switch and a GaAs MMIC Switch for Reconfiguring the Operating Frequency of a Vivaldi Antenna

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***Abstract*—This article proposes a novel liquid switch to reconfigure the operating frequency of a frequency-independent antenna. A Vivaldi antenna using a low-cost GaAs MMIC RF switch is used as a landmark to compare the measured results. Two prototypes are measured in an anechoic chamber and the results have been compared. The antennas operate in two modes: low-band mode at 3 GHz with 11 dBi of gain and high-band mode operating at 4.5 GHz with a measured gain of 10.8 dBi. The reconfigurable Vivaldi antenna proposed here presents high isolation between operating bands, a minimum of 12 dB, while maintaining high gain and stable radiation pattern which is suitable for cognitive radio applications.**

I. Introduction

Because of the rapid proliferation of wireless communications systems, the electromagnetic spectrum has become heavily congested. To address this challenge, new wireless communication systems are required to be cognitive and reconfigurable [1]. Currently, antennas are a critical part of the communication systems. Although big limitations appear because of their incapability to be dynamically adapted to changing environments [2], [3].

By selecting the bands of interest in an ultra-wideband antenna, the reconfiguration process of the operating band of an antenna can be facilitated. Narrowband antennas can only operate in a narrow frequency range and impedance matching may be complicated when functioning in a wide frequency range. The frequency-independent Vivaldi antenna is a good candidate for a frequency-reconfigurable antenna. Vivaldi antennas provide high gain and stable beamwidth and consistent direction of the main lobe in their wide operating band [4].

Some work on reconfigurable Vivaldi antennas has been reported in [5]–[7]. Resonating rings are introduced to a Vivaldi antenna to obtain a tuning narrow band or a wide band. Although good isolation between bands is achieved in these designs, the gain is compromised by less than 5 dB.

To provide high isolation and preserve high gain in the Vivaldi antenna an impedance tuning mechanism is proposed in this paper. First, RF switches are considered. In [8] RF-MEMS switches are proposed because of their low insertion loss, high isolation and wide operating bandwidth. But they prove to be difficult to integrate in the design as they require a wire bonding machine, the switches are ESD sensible and require an expensive 90 V driver to operate them. Therefore, a low-insertion loss GaAs MMIC switch is proposed for design A. Another design is proposed to overcome the issues arisen from design A: insertion losses, extra cost the system, the switch biasing lines affect the antenna performance and are not easily integrated in the design. Thus, design B is proposed using a novel liquid switch mechanism. An ionised solution is used as conductive liquid to operate as the RF switch in design A. Ionised solutions have been demonstrated to be feasible for antenna design as reported in [9]–[11].

II. Antenna Geometry

The proposed antenna is designed on a single microwave substrate, as shown in Fig. 1. The dielectric substrate used is 0.762 mm Taconic RF-43. The top layer presents a microstrip feed-line ended with a stub. The stub matches the impedance of 50 Ω at the input port to the optimum impedance in the slot. The stub-to-slot intersection is highlighted in red. One RF switch is introduced in the slot. The position of this switch determines the effective length of the stub for maximum signal coupling at the stub-to-slot intersection. Table I indicates the design parameters and their values.

The switch controls the current path while setting maximum coupling in the stub-to-slot intersection to produce a higher operating band. To operate in the lower band, i.e. switch is OFF, the switch enables the current to flow through the full length of the slot allowing the current to couple to the open end of the Vivaldi antenna. For the high band mode, i.e. switch is ON, the length of the slot is shorter coupling the current only at higher frequencies. Outside the operating frequency band, the current is not coupled providing high band isolation.

A. *Design A using a GaAs MMIC RF switch*

Design A is proposed using a low-insertion loss GaAs MMIC switch. Hittite HMC550AE is considered as it provides adequate technical specifications from DC to 6 GHz. A table summarising the main specifications of this switch is presented in Table II [12].

Compared to other switching technologies, GaAs MMIC switches have an acceptable insertion loss and bandwidth, one of the fastest switching speeds and low actuation voltage and bias current. Despite their isolation, which is close to a

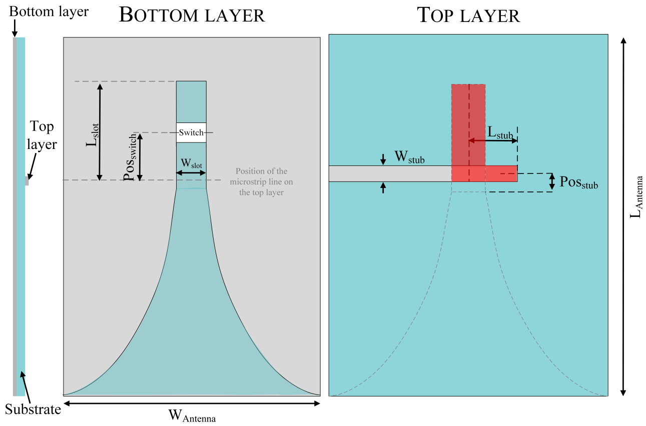


Fig. 1. Proposed geometry for a reconfigurable Vivaldi antenna.

TABLE I
VALUE FOR THE DESIGN PARAMETERS

Design parameters	*Dimensions (mm)*
$\mathbf{L}_{antenna}$	250.0
$\mathbf{W}_{antenna}$	150.0
$\mathbf{L}_{slot}$	60.0
$\mathbf{W}_{slot}$	1.22
$\mathbf{Pos}_{switch}$	40.0
$\mathbf{L}_{stub}$	7.98
$\mathbf{W}_{stub}$	1.5
$\mathbf{Pos}_{stub}$	15.8

TABLE II
CHARACTERISTICS OF THE HMC550AE GAAS MMIC SWITCH

Insertion loss at 1 GHz	0.7 dB
Isolation at 1 GHz	25 dB
Switching speed	40 ns
Bandwidth	DC - 6000 MHz
Actuation voltage	1.2-5 V
Bias current	0.2 μA

PIN diodes isolation, it is a good candidate for reconfigurable antennas.

A separating cut is required at the end of the slot to separate the two wings of the Vivaldi antenna for the RF switch to operate properly at DC. Fig. 2 presents the fabricated prototype of design A. The prototype is fabricated using an etching technique in the university's workshop. A digital control circuit board is designed to operate the RF switch. The RF switch is manually soldered at the top layer and it connects through vias to the slot at the bottom layer.

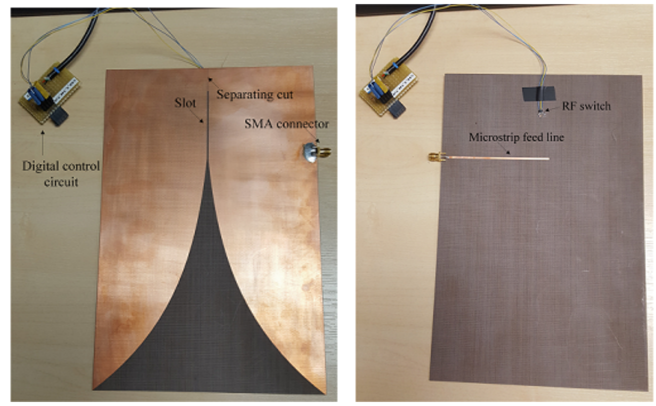
The measured S-parameters of the proposed RF switch are embedded in a commercial full-wave EM simulation software (CST Microwave Studio [13]) to obtain results closer to reality.

B. Design B using a novel liquid switch

A novel liquid switch is considered in design B. The liquid switch is first designed using CST Microwave Studio as shown in Fig. 3. The CAD design is exported and 3D printed using a Formlabs Form1+ SLA 3D printer. It is attached into the Vivaldi antenna at a specific location to match a higher band. If this location is adjusted the operating frequency at the higher band can be tuned. The ionised solution is 2 mol KCl water solution. Its permittivity properties are measured in the lab using Agilent 85070E Dielectric Probe Kit and imported into CST for optimisation.

Currently a syringe is used to introduce the ionised solution into the 3D-printed container. In practical case, a micropump or a diaphragm system can be adopted to automatically tune the operating frequency.

Fig. 4 displays the fabricated prototype for design B. The prototype is measured in the university's anechoic chamber and the results are presented in Section III.



(a) Bottom layer (b) Top layer

Fig. 2. Bottom layer and top layer of the prototype fabricated of design A.

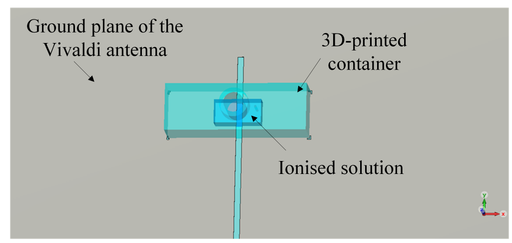
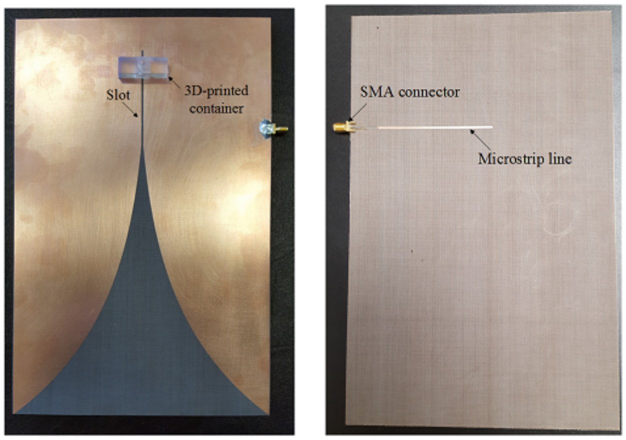


Fig. 3. Liquid switch designed in CST.

III. MEASURED RESULTS

Fig. 5 compares the measured reflection coefficient and Fig. 6 compares the gain for design A using a GaAs MMIC switch and design B using a novel liquid switch to control the operating band. HB indicates high band and LB indicates low band. Table III displays the measured results in low-band mode and Table IV presents the measured results in high-band mode.

Looking at the reflection coefficient, there is a frequency shift. Design B is matched 400 MHz lower in frequency than design A. This is because of the effect of the case in the slot and the ionised solution (measured 25 S/m at 20°C) not being as conductive as copper ($5.96{\cdot}10^7$ S/m at 20°C),



(a) Bottom layer (b) Top layer

Fig. 4. Bottom layer and top layer of the prototype fabricated of design B.

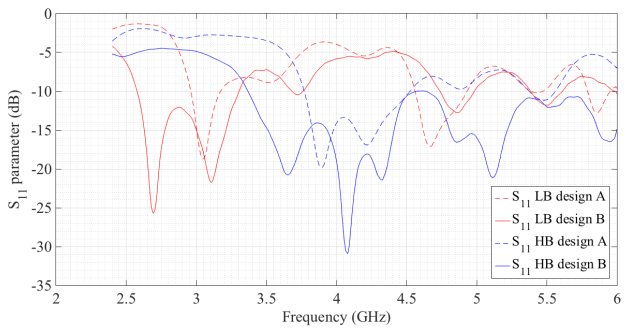


Fig. 5. Measured reflection coefficient compared for design A and design B.

TABLE III
LOW-BAND MEASURED RESULTS FOR DESIGN A AND DESIGN B

	Design A	*Design B*
Operating frequency	3.1 GHz	3.15 GHz
Gain	10.5 dBi	11 dBi
Isolation	14 dB	12 dB

making the liquid like an absorber and matching it in lower frequencies. However, the gain at these lower 400 MHz is very low compared to the rest of the band. Therefore, this shift is not critical as design B still operates at the frequencies of interest: 3 GHz and 4.5 GHz. From 4.6 GHz and up the high band of design B is again well matched at 5 GHz which design A is not. This can be because of the losses in the liquid material and a poor CST model of the liquid switch which carries the error at higher frequencies. For the gain the main difference is the shift for the rejected frequency in low-band mode. This is because of the liquid case affecting the slot length at the rejected frequencies.

IV. CONCLUSION

The frequency-independent Vivaldi antenna is proposed as the basis for a frequency reconfigurable antenna design. To tune the operating frequency two designs are proposed. Design A introduces an RF switch in the slot to match the band of interest. While design B uses a novel liquid switch created to provide higher flexibility and lower impact on the antenna performance due to biasing lines. The prototypes of these two designs are measured in an anechoic chamber and present good agreement.

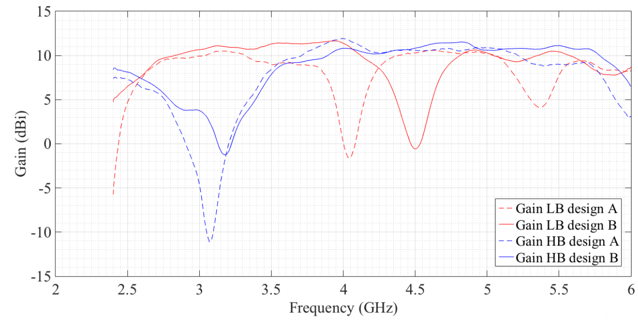


Fig. 6. Measured gain compared for design A and design B.

TABLE IV
HIGH-BAND MEASURED RESULTS FOR DESIGN A AND DESIGN B

	Design A	*Design B*
Operating frequency	4 GHz	4.5 GHz
Gain	12 dBi	11 dBi
Isolation	22 dB	12.5 dB

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