Broadband microstrip patch antenna with V-slot

Gh. Rafi and L. Shafai

Abstract: A microstrip antenna incorporating a V-shape slot on its patch is introduced and studied for its impedance bandwidth and radiation characteristics. It is shown that the antenna is inherently broadband, and by optimising the V-parameters its performance can be improved considerably over that of a U-slotted patch. Its stacked configuration is also investigated, using both a conducting patch and another V-slotted patch. Bandwidths as high as 54% are achieved with stable pattern characteristics, such as gain and cross polarisation, within its bandwidth. A detailed investigation is conducted and the effect of all its parameters, such as the substrate dielectric constant and thickness as well as the V-slot length, position, width and angle, are determined and discussed. An experimental study confirms the simulation studies.

1 Introduction

A microstrip patch antenna is a simple structure that is easy to fabricate and form into arrays for higher gains. It is, however, a resonant device that limits its impedance bandwidth to a few per cent. For this reason much effort is made to develop techniques and find configurations to broaden its impedance bandwidth. The coupled resonator approach has been the most successful, where stacked patches [1], a combination of patch and slot [2], or patch and a bent probe are used [3]. The U-slotted patch is a popular design, where the resonant slot is bent to a U-shape and placed on the patch thereby obtaining a broadband operation with a single-layer substrate [4–6].

Bandwidths as high as 30% with a coaxial feed are obtained [4]. The U-shape of the slot is not unique and other slot shapes may also be used. For instance, in [7] a circular arc-shape slot is used and an impedance bandwidth of 30%, the same as that of the U-slot, is obtained. Higher impedance bandwidths of about 45% are also obtained using a U-slotted patch, but only when stacked with another parasitic patch [8] or another U-slotted patch [9].

In this study the slot shape is changed to a truncated V, to introduce the V-slot arm angle as an additional parameter over the U or circular arc-shape slots, for further bandwidth optimisation. Both single-layer and stacked configurations are investigated. The single-layer case is the fundamental configuration, for which the patch and slot parameters are modified and the antenna performance is studied in detail. Bandwidths as high as 36.5% are obtained. For the stacked case two different configurations are investigated. In one case, the V-slotted patch is stacked by a conventional rectangular patch and its performance is again investigated, increasing the antenna bandwidths to 47%. In the second case, the V-slotted patch is stacked by another V-slotted patch. This antenna has more coupled resonators and more parameters to change, and has potential for pattern shaping and broader bandwidths. It requires extensive investigation, and in this study bandwidths as high as 54% are obtained. Unlike many other broadband microstrip antennas, this antenna provides stable gain and polarisation within its bandwidth, with accepted cross-polarisation levels. The simulation studies were conducted using Ansoft Ensemble 8 software, and verified by sample experimental models. The fabricated antennas were tested in the antenna laboratory of the University of Manitoba.

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2 Single-layer antenna

The antenna geometry is shown in Fig. 1, which is a probe-fed microstrip antenna with a truncated V-slot cut on its patch. It is similar to the U-slotted patch antenna, where the truncated V adds additional parameters for the antenna optimisation. They are the V arm angle α, and the inter-relationship between the base width W_V and V arm lengths L_V. These additional parameters enable the control and optimisation of the patch input impedance, without moving the feed location. Consequently, throughout this study the feed probe has been maintained at the patch centre, or close to it. This improves the symmetry of the antenna geometry and helps in eliminating the higher-order modes.

Using Ansoft Ensemble 8, a parametric study was conducted to determine the optimum parameters for a wideband operation. Since this antenna is a variation of the U-slotted patch antenna their return loss and input impedance are compared in Figs. 2 and 3 for similar

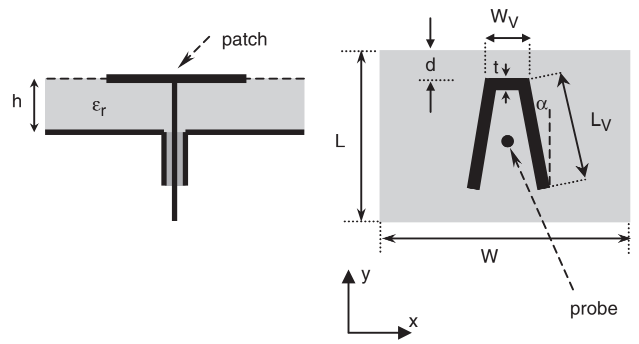

Fig. 1 *Geometry of single-layer rectangular microstrip patch antenna with truncated V-slot*

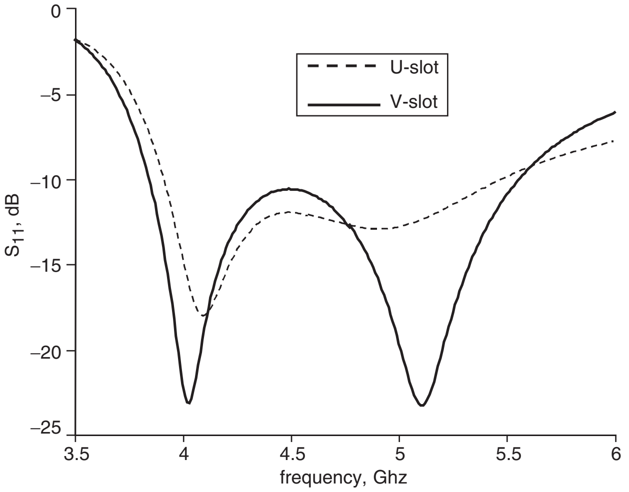

Fig. 2 *Return loss for V-slot and U-slot microstrip patch antennas*
$\varepsilon_r = 1.0006$, $L = 35.5$ mm, $W = 26$ mm, $\alpha = 7.5°$, $L_V = 20.7$ mm, $W_V = 8.8$ mm
$d = 2.3$ mm, $h = 5.8$ mm. Dimensions of U-slot antenna as [5]

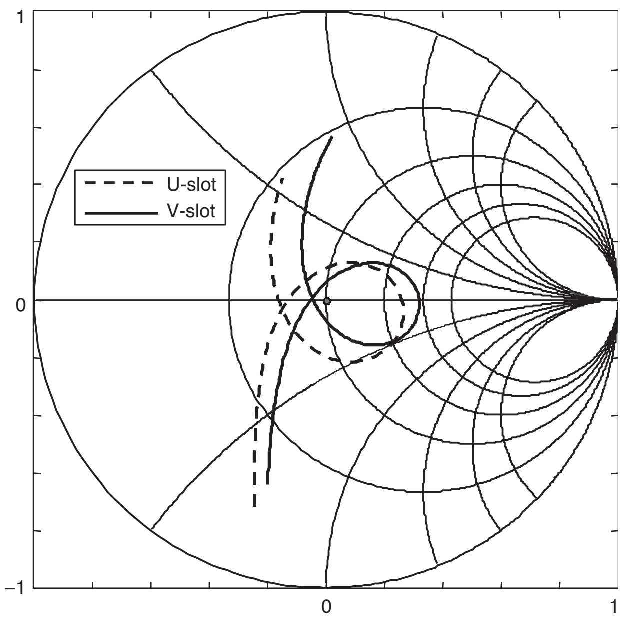

Fig. 3 *Impedance plots for V-slot and U-slot microstrip patch antennas data as Fig. 2*

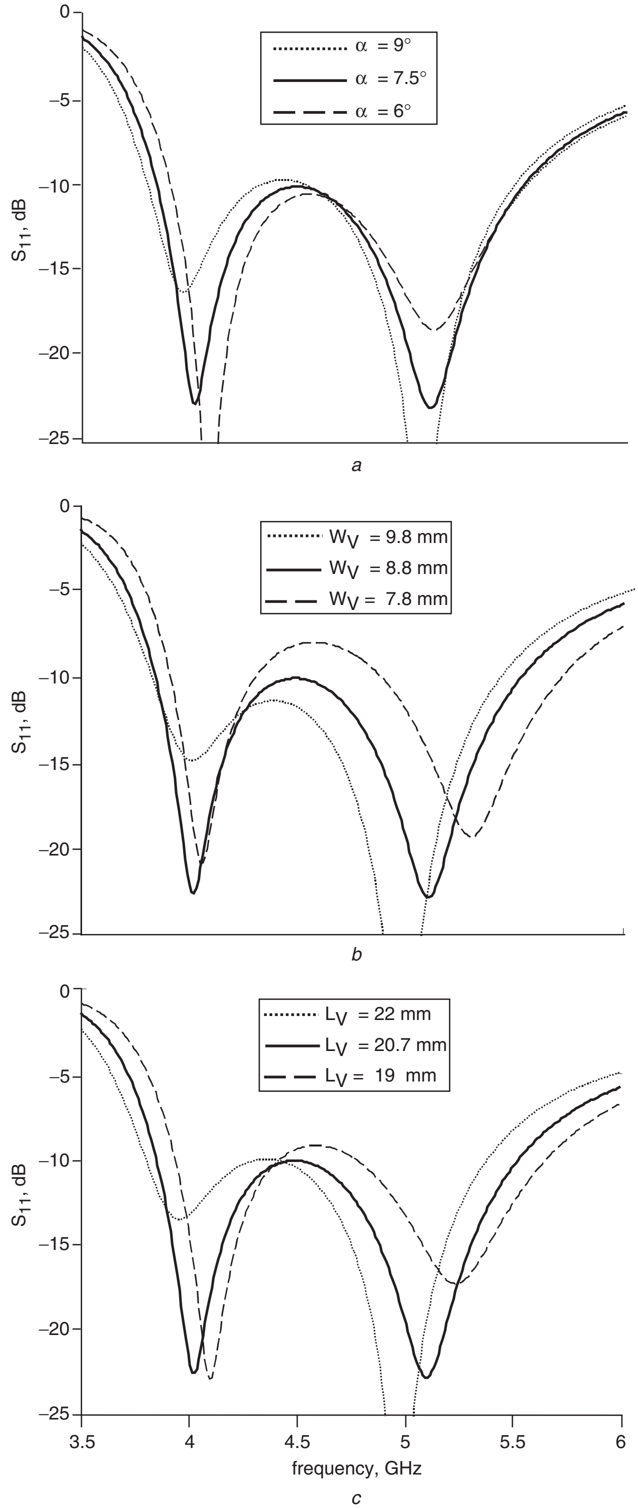

Fig. 4 *Effect of V-slot parameters on the return loss of V-slot microstrip patch antenna, data as Fig. 2*
a Angle
b Width
c Length

dimensional parameters. The proposed V-slot antenna provides a somewhat wider bandwidth of 36.5% compared with 30% of the U-slot antenna, and a symmetric resonance which is due to more controlled location of the impedance loop on the Smith chart, as shown in Fig. 3. This is clearly shown in Fig. 4, where the return losses are plotted for different V arm angles, keeping other parameters constant. Its effect on the bandwidth is small, but it controls to some degree the impedance-loop location and orientation on the Smith chart. One can therefore modify the input resistance and phase without significantly altering its impedance magnitude and the antenna bandwidth.

Note also that this parameter affects mostly the lower resonance frequency of the antenna. It can therefore be used to tune the antenna bandwidth without significantly altering the upper end of its frequency band. This is understandable, since the presence of slot restricts the patch currents, at its lower resonance frequencies, between the slot arm and patch vertical edge [7]. Increasing the slot arm angle increases the path length and thus lowers its resonance frequency. The effect of other parameters, namely its truncated width W_V and length L_V, were also investigated and are shown in Figs. 4*b* and 4*c*. They influence both lower and upper resonance frequencies. Since both these parameters control the slot length, increasing them lowers the resonance frequencies. They can also be used to tune the antenna bandwidth.

The simulated return loss of the antenna in Fig. 1 is compared with the measured data in Fig. 5. The

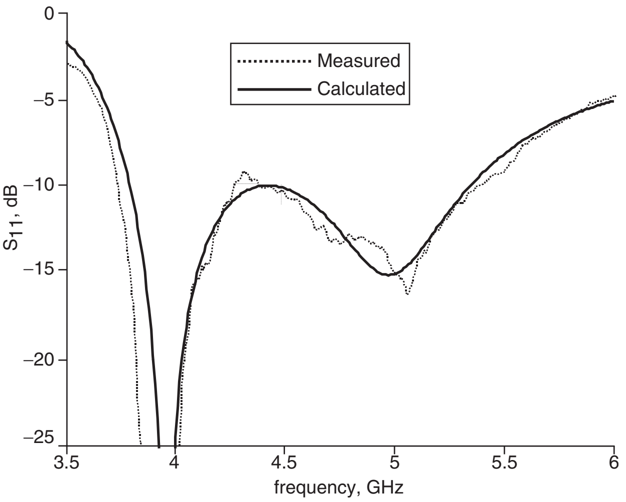

Fig. 5 *Comparison of simulated and measured return loss for V-slot microstrip patch antenna*
$\varepsilon_r = 1.1$, $L = 35.5$ mm, $W = 26$ mm, $\alpha = 6°$, $L_V = 20.7$ mm, $W_V = 8.8$ mm
$d = 2.3$ mm, $h = 5.8$ mm, Finite ground plane size: $W_G = L_G = 100$ mm

experimental antenna was fabricated manually using a copper tape on a construction-grade foam, having a relative permittivity of about $\varepsilon_r \cong 1.1$ and a 100×100 finite ground plane. Considering the construction method the agreement between the simulated and experimental results is satisfactory. The simulated and measured H-plane radiation patterns of the test antenna are compared in Figs. 6*a* and 6*b*, at 4 and 5.2 GHz, and show that the antenna is well matched at the two frequencies. Aside from a slight gain difference of about 0.5 dB, the two copolar patterns are almost identical. This small gain difference can be easily attributed to experimental gain error using a standard-gain horn. The measured cross-polarisations levels are almost the same but their shapes are slightly different. The E-plane patterns showed a slight beam shift due to the effect of the V-slot on the patch, otherwise they were nearly identical to the H-plane ones. Thus they are omitted for brevity. Also the cross polarisation in the E-plane is negligible.

3 Stacked configurations

In this Section the performance of the single-layer V-slotted antenna is investigated when stacked with a simple rectangular patch, or another V-slotted patch antenna. In general, stacking microstrip patches couples their resonant frequencies and thus influences their input impedance. In particular, as with coupled tuned circuits, when the resonant frequencies are close and the coupling coefficient is relatively weak a significantly wide bandwidth can be obtained. In the present case, stacking with a simple patch adds another resonance to the antenna, while stacking with another V-slotted patch adds another two resonances. Consequently these stacked antennas can provide significantly wider bandwidths, especially the stacked V-slotted antenna that adds two additional resonances and provides a superior performance.

3.1 Case I: V-slotted patch stacked with solid patch

The geometry of a V-slotted patch stacked with a simple patch is shown in Fig. 7. Its return loss against frequency is compared in Fig. 8 with that of a similar stacked U-slotted patch antenna.

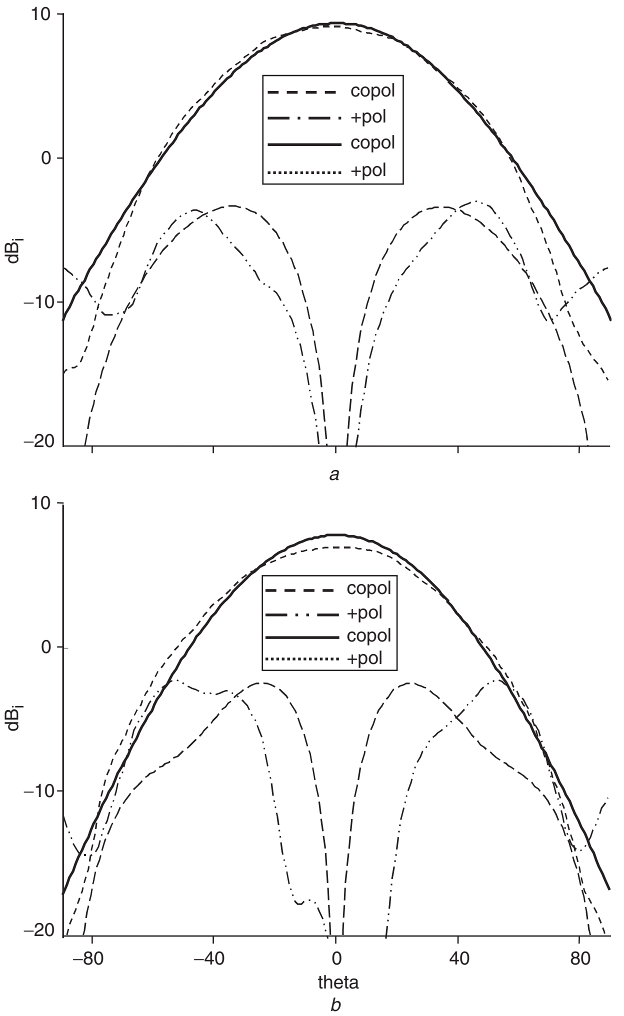

Fig. 6 *Comparison of simulated and measured H-plane ($\varphi = 0$) patterns $\alpha = 6°$, data as Fig. 2*
a 4 GHz
b 5.2 GHz

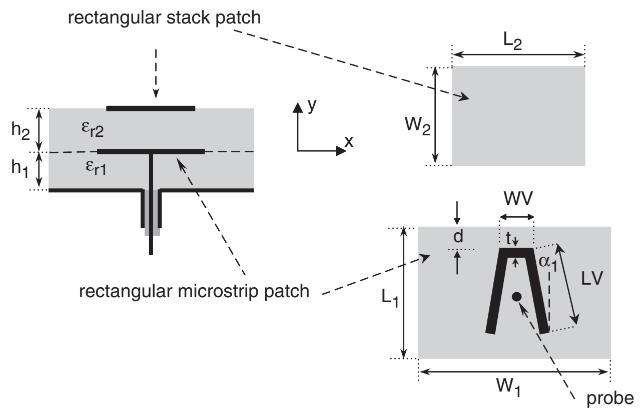

Fig. 7 *Geometry of a double-layer V-slotted rectangular patch stacked with simple rectangular patch*

The bandwidth of the V-slotted patch is enhanced to 47%, from the 40% bandwidth of the stacked U-slotted patch. Also, the V-slotted patch shows nearly balanced resonant frequencies; significant improvements for the V-slot antenna over the U-slot. Note also that the dimensional parameters of the lower V-slotted patch and its V-slot in Fig. 8 are almost the same as those of single-layered V-slotted patch of Fig. 2. Consequently even after stacking with another patch, its return loss behaviour remains very similar to that of the single-layered one in Fig. 2. The

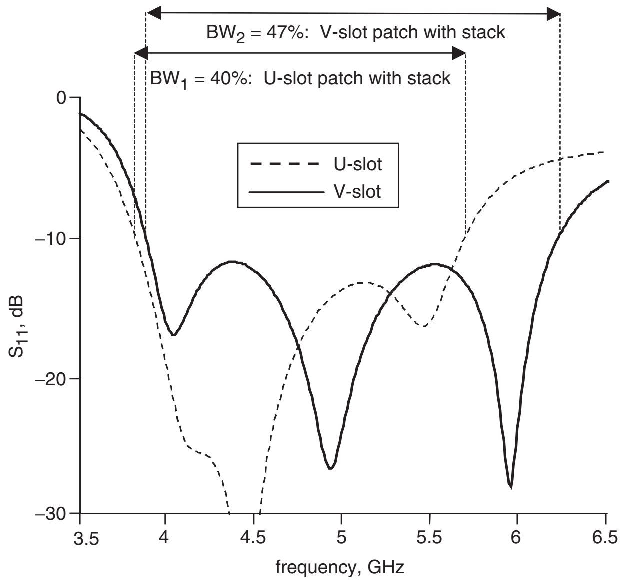

Fig. 8 *Return loss for U-slot and V-slot microstrip patch antennas stacked with rectangular Patch*
$\varepsilon_{r1} = 1.05$, $L_1 = 37\,\mathrm{mm}$, $W_1 = 28\,\mathrm{mm}$, $\alpha_1 = 10^\circ$, $L_V = 19\,\mathrm{mm}$, $W_V = 7.2\,\mathrm{mm}$
$d_1 = 6.3\,\mathrm{mm}$, $h_1 = 5\,\mathrm{mm}$, $\varepsilon_{r2} = 1.05$, $L_2 = 26\,\mathrm{mm}$, $W_2 = 19.4\,\mathrm{mm}$, $h_2 = 5\,\mathrm{mm}$. Dimensions of U-slot antenna as [7]

stacking has introduced an additional resonance beyond 5.6 GHz, the upper frequency of the single-layered antenna, increasing it to about 6.25 GHz.

Since this antenna has a large number of dimensional parameters, a detailed presentation of its performance is not provided here. Only sample results are included. The low-frequency behaviour was found to be similar to the single-layer antenna and the V-slot angle affected only the low-frequency end. Its results therefore are not included. However, the slot length L_V and truncated width W_V, having influence on the upper frequency end of the single-layer antenna, also influence the upper frequency of the stacked one. They are shown in Figs. 9 and 10, respectively. The slot length in Fig. 9 surprisingly has no effect on the low-frequency end. Figure 10, however, shows that W_V affects both low and high frequencies.

To verify the simulation results the return loss of antenna is compared with measurement data in Fig. 11. The antenna was fabricated manually using copper tapes on foam plates,

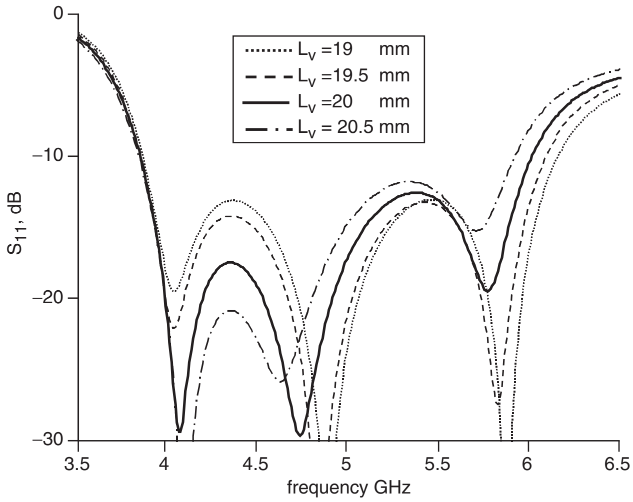

Fig. 9 *Effect of V-slot length on return loss of antenna in Fig. 8*

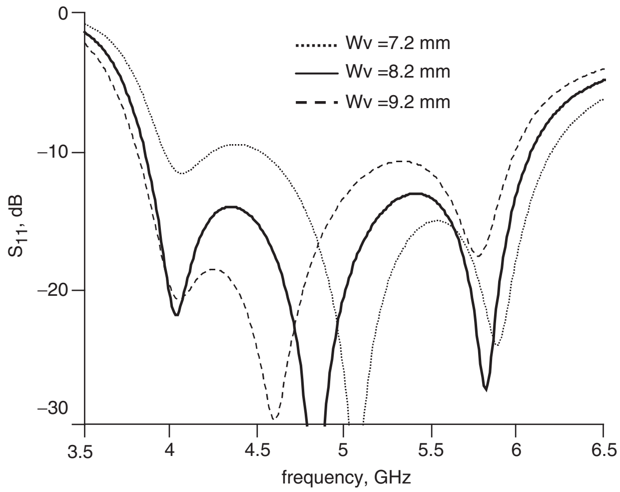

Fig. 10 *Effect of V-slot width on return loss of antenna in Fig. 8*

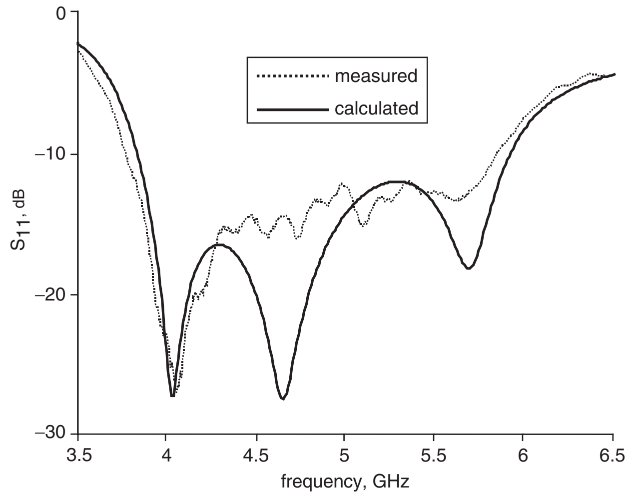

Fig. 11 *Comparison of simulation and measured return loss for V-slot microstrip patch antennas with simple stack*
$L_V = 20\,\mathrm{mm}$, $\varepsilon_{r1} = \varepsilon_{r2} = 1.1$, other parameters as Fig. 8

and its return-loss plot shows slight differences with the simulated one. But the bandwidths are almost identical.

3.2 Case II: Two V-slotted stacked patches

The effects of another truncated V-slot on the stacked parasitic patch are discussed in this Section. Generally the interaction of the slot with its own patch forms two resonance frequencies. Thus, stacking two V-slotted patches will, at least, provide four resonant frequencies. Careful optimisation is necessary to appropriately select these frequencies and control their coupling levels to enhance the antenna bandwidth without splitting the operation band. Figure 12 shows the antenna geometry. Both the lower and upper patches have truncated V-slots of different parameters but the upper patch and its V-slot are smaller than the corresponding lower ones. Also, after some optimisation, it was found that a better impedance bandwidth can be obtained when the two V-slots are inverted with respect to each other. The antenna has a large number of parameters for optimisation, and not all investigation results are provided here.

A sample return-loss plot is provided in Fig. 13 to compare the input impedance bandwidth of this antenna with those of the previous cases when V and U-slotted patches were stacked with conventional solid patches. The improvement in the bandwidth is evident. The dual stacked

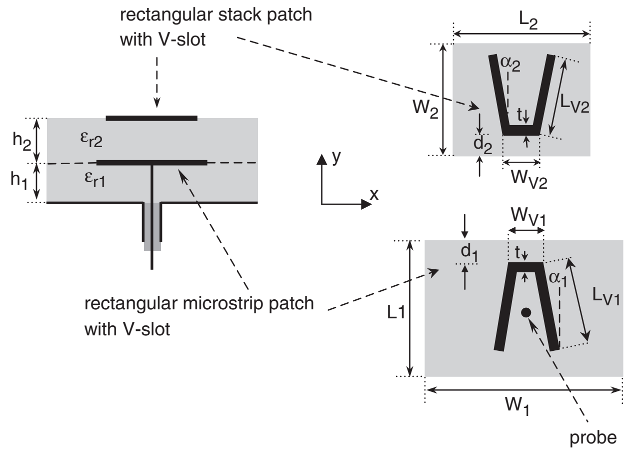

Fig. 12 *Geometry of double-layer, V-slotted rectangular microstrip patch stacked with another V-slotted patch*

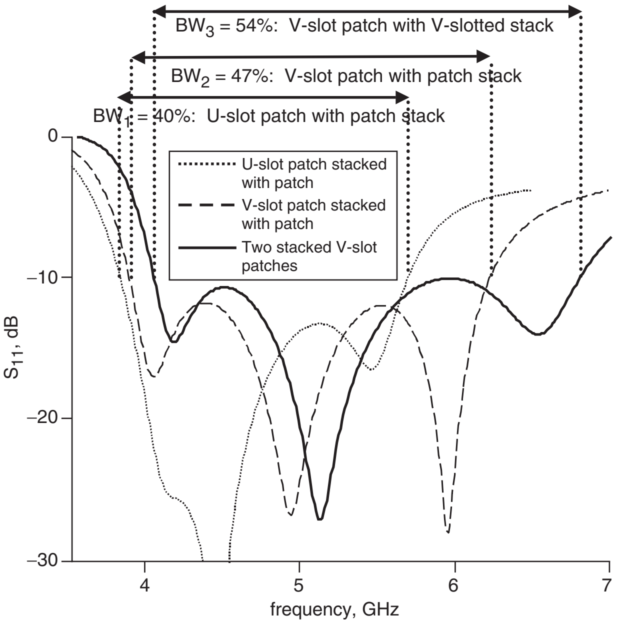

Fig. 13 *Return loss of two stacked V-slotted patches comparised with V- and U-slotted patch satcked with single patch*

$\varepsilon_{r1} = 1.0006$, $L_1 = 37$ mm, $W_1 = 28$ mm, $\alpha_1 = 7°$, $L_{V1} = 19$ mm, $W_{V1} = 8$ mm

$d_1 = 6.3$ mm, $h_1 = 5$ mm, $\varepsilon_{r2} = 1.0006$, $L_2 = 26$ mm, $W_2 = 19.4$ mm $\alpha_2 = 24°$, $L_{V2} = 18$ mm, $W_{V2} = 6$ mm, $d_2 = 1.7$ mm, $h_2 = 5$ mm, other dimensions as Fig. 8

V-slotted patches case provides an enhanced bandwidth of 54%, as compared with the 47 and 40% bandwidths of the previous stacked cases. Here the upper patch and its truncated V-slot, being smaller than the corresponding lower ones, influence the upper frequency of the antenna. The lower frequency is controlled primarily by the lower patch and its slot. In particular, since the V-slot length affects the upper frequency of the antenna, the upper frequency for this stacked case can be fine-tuned by the V-parameters of the stacked patch. A sample case is provided in Fig. 14, where the V-slot angle θ_2 is used to modify the upper frequency of the antenna. The lower frequency is mostly influenced by the parameters of the lower patch length and its slot, as shown previously. However, such simple generalisations of the slot or patch parametric effects are not valid for all other parameters, as the two patches and their slots are highly coupled and influence each other's effects. These simple rules can be used to select starting parameters for further optimisations.

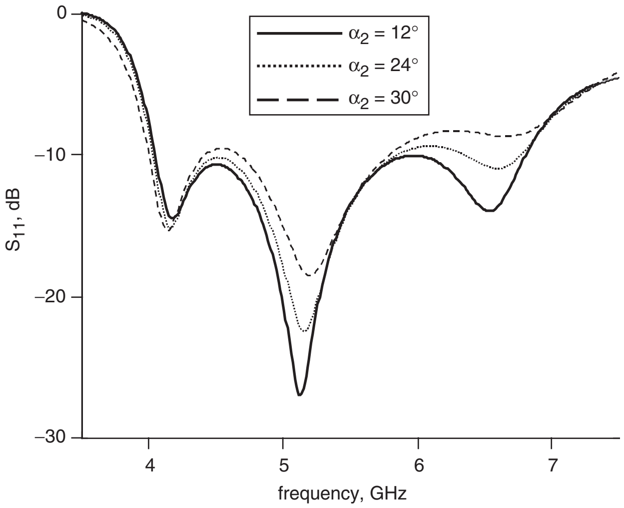

Fig. 14 *Effect of second V-slot angle on return loss; dimensions as Fig. 13*

4 Conclusions

Properties of the V-slotted rectangular microstrip patch antenna were investigated. It was shown that modifying the U-slot to a truncated V-slot increases the antenna bandwidth to around 36.5%. It also adds additional parameters, the V-angle and the interrelation of its truncation width and arm length, that can be used for optimising its performance. Its stacked configurations were also investigated. Stacking with a rectangular patch increased its bandwidth to about 47%, again higher than the bandwidth of a stacked U-slotted antenna. The highest bandwidth of about 54% was obtained by stacking two V-slotted patches. The V-slotted patch provides the large bandwidth with two resonances. Stacking with a rectangular patch adds one additional resonance and increases the bandwidth at the upper frequency end, while stacking with another V-slotted patch adds two more resonances and again extends the antenna bandwidth further at the upper frequency end. In this manner the performance of the stacked antennas can progressively be estimated from that of the single V-slotted patch. To verify the simulation results, experimental models using foam substrates were fabricated and tested. The wide bandwidths were confirmed. The measured radiation patterns also confirmed the simulations. To summarise, Table 1 is presented to compare the bandwidth of the single and dual-layer V-slotted patch antennas.

Table 1: Comparison of bandwidth of single and dual-layer microstrip V-slotted patch antenna

Antenna type	Antenna I	Antenna II	Antenna III
Simulated	36.5%	47%	54%
Measured	37%	47%	54%

Antenna I: Single-layer V-slot patch antenna (Fig. 1).
Antenna II: V-slotted patch stacked with conventional patch (Fig. 7).
Antenna III: Two V-slotted stacked patches (Fig. 12).

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