

LOW COST, MULTI-BEAM ANTENNA FOR WLAN APPLICATIONS

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Abstract. *A low cost, low profile, multi-sector switched beam antenna, well suited for domestic in-home networking in the 5 GHz band is proposed. The antenna is based on using four end-fire Vivaldi-type antennas distributed at 90° from each other on a single flat microstrip substrate and associated to an integrated 1 to 4 ports switch. The switch concept is based on the control of the microstrip to slotline transition used in the feeding of the Vivaldi radiators, by placing PIN diodes at the end of the microstrip feeding lines. The design of the switch system is first presented and compared with measurements, then the 4 sector switched beam antenna is designed and tested. The obtained measurements agree well with simulations.*

I. Introduction

The explosion of wireless local area networks (WLAN) is foreseen in the coming years. Many devices complying with Bluetooth, Home RF, IEEE 802.11b operating at the 2.4GHz band are already in the consumer market. At 2.4 GHz , only 83 MHz band is available for all these systems and it will be very soon congested. It is likely that the next generation of high speed wireless networks, operating in the 5 GHz band, where wider and more cleaner bandwidth is available will come into view very quickly. Furthermore, the new ETSI Hiperlan2 [1], IEEE 802.11a [2] and ARIB HiSWANa [3], 5 GHz standards could support bit rates up to 54 Mbps opening the door to new applications such as streaming video for high definition TV and interactive gaming.

In order to compensate the higher signal attenuation observed at 5 GHz , 5 to 10 dB more Equivalent Isotropic Radiated Power (EIRP) is allowed by regulations in the high sub-bands of the allocated spectrum [1,2,4]. Taking into account the high linearity demand placed on the power amplifier, imposed by the COFDM modulation used in the 3 standards, it is not reasonable from a complexity and cost point of view to use all the permitted power at the output of the amplifier, in particular for consumer applications. The use of directive antennas to improve the EIRP without the need of costly power amplifier could be very attractive. Directive antennas are also well suited for interference reduction and the mitigation of the multipath frequency fading problem. However, the size of the antenna increases with directivity and several beams with alignment capabilities are required for the coverage of the full 360° space.

In this paper a low cost, low profile, 4 sector switched beam antenna well suited for domestic in-home networking in the 5 GHz band is proposed. First, the design of the 1 to 4 ports switch is presented and validated by measurements, then a complete antenna system based on the developed switch is realized and tested.

II. Antenna structure description

A schematic of the 4-sector switched beam antenna is shown in Figure 1. Each sector is covered by a Vivaldi antenna with a 3dB-beamwidth of 90°, so a 360° coverage is possible. Each Vivaldi is fed through a microstrip to slotline transition described by Knorr [5]. The microstrip $\lambda/4$ stub is terminated by a PIN diode for the control of the microstripline/slotline transition. The state of the diode is commanded by an individual control voltage V_{cc} . and allows to set a short circuit (SC) or an open circuit (OC) at the end of the stub. This allows to select one “active” branch (diode OFF) and three “passive” branches (diode ON). A DC-Block is also placed between the DC polarization circuit and the RF feed.

In order to insure 90° beamwidth for a single sector, using a 0.81mm height Rogers 4003 substrate, the dimensions (in mm) of the Vivaldi with circular profile are chosen as: $L=37.5$ (length of the profile), $X=40.6$ (aperture) and $R=45$ mm (radius of the profile) (cf. Figure 2).

III. Switch design

III.1 Switch concept validation

Firstly, a single branch ended by an ideal SC or OC was simulated using IE3D software from Zeland to validate the switch working of the transition (cf. Figure 3). In this simulation, the Vivaldi antenna was replaced by a second microstrip to slotline transition in order to get the Sij parameters (matching, transmission and isolation). Port 2 is 100Ω loaded. It can be seen on Figure 4 the good working of this single branch switch over a wide frequency bandwidth.

III.2. Design of a 1 to 4 ports switch using ideal PIN diodes

A breadboard with 4 identical branches described in III.1 has been realized. One stub is terminated by an ideal OC, while the 3 others are terminated by a metallized via. Measurements are done with a network analyzer (cf. Figure 5). Port 1 is linked to the RF feed, port 2 to the active branch and ports 3, 4, 5 to the passive branches. In this configuration, 195MHz bandwidth is achievable at a center frequency $f_c=5.63\text{GHz}$ ($\approx 3.5\%$). An estimated value of the insertion losses in the active branch is around 1.5dB, and is quite constant over the matching bandwidth. Isolation is better than 24dB over the whole matching bandwidth. This level could be reduced further by optimizing the stub length in order to center the maximum isolation frequency and the matching bandwidth center frequency. Simulation results (not represented) were very close to measurements.

III.3 Design of a 1 to 4 ports switch using real PIN diodes

A similar breadboard has been realized with real diodes (HSMP-489B PIN diodes from HP) at the end of the stub. The length of the stub had to be shortened to compensate the introduction of the diode (8.3mm \rightarrow 5.5mm). As can be seen on Figure 6, the bandwidth is only 120MHz (2.1% @ $f_c=5.63\text{GHz}$). This bandwidth reduction is due to the diode non-symmetric frequency response whether it is ON or OFF, which also leads to a worse matching level. Estimated losses in the active branch are now about 2.3dB (0.8dB excess loss due to the diode). Isolation is still better than 23dB over the whole matching bandwidth, but a discrepancy between branches can be noticed in these curves, certainly due to the soldering of the diodes. Simulations including diodes S-parameters at the end of the stubs were also performed, and gave similar results (not represented).

The use of $\lambda_g/2$ rather than $\lambda_g/4$ stubs can be considered in order to decrease the DC consumption (one diode is ON and three are OFF).

IV. Antenna system design and radiation pattern measurements

Four Vivaldi antennas as described in II were added to the circuit of paragraph III.3 in order to get a 4-sector switched beam antenna (cf. Figure 7). The overall dimensions of the realized antenna structure is a 140mm square. The matching of the structure is quite the same whatever the active branch (cf. Figure 8). As seen for the feeding circuit, a 120MHz bandwidth ($\approx 2.1\% @ 5.63\text{GHz}$) is measured. With a re-tuning of the center frequency, the obtained bandwidth should be sufficient to cover the upper band of IEEE 802.11a (5.725-5.825GHz). Figure 10 presents the patterns of the structure versus the active branch. As expected, the obtained 3dB-aperture is 90° for each Vivaldi. The small tilt and asymmetry in the patterns may come from the asymmetric groundplane on both sides of the Vivaldis.

Due to its low profile, this antenna system is well suited for an integration in a Set Top Box (STB) or at the top of a TV set. The peripheral location of radiators allows a positioning of the RF front end in the middle of the board.

V. Conclusions

A multi-beam antenna composed of four end-fire Vivaldi-type antennas distributed at 90° from each other and associated to an integrated 1 to 4 ports switch has been designed. The switch concept based on the control of the microstrip to slotline transition used in the feeding of the Vivaldi radiators has been validated by simulations and measurements. A prototype of the antenna has been realized. A 90° 3dB-aperture radiation pattern was measured for each sector, allowing a full 360° coverage. The low profile of the proposed antenna allows it to be integrated in a STB or at the top of a TV set.

References

[1] ETSI, TS 101 475 v1.1.2A (2001-02), "Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Physical (PHY) Layer".

[2] IEEE Std 802.11a-1999 (Supplement to IEEE Std 802.11-1999), "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5GHz Band".

[3] ARIB STD-T170 & STD-T171, "Low power data communication systems broadband mobile access communication system (HiSWANA & CSMA)", First Edition, 14 December 2000.

[4] IEEE Std 802.11b-1999 (Supplement to ANSI/IEEE Std 802.11, 1999 Edition), "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4GHz Band".

[5] J.B. Knorr, "Slot-line transitions", IEEE Trans. on Mic. Th. and Tech., pp.548-554, May 1974.

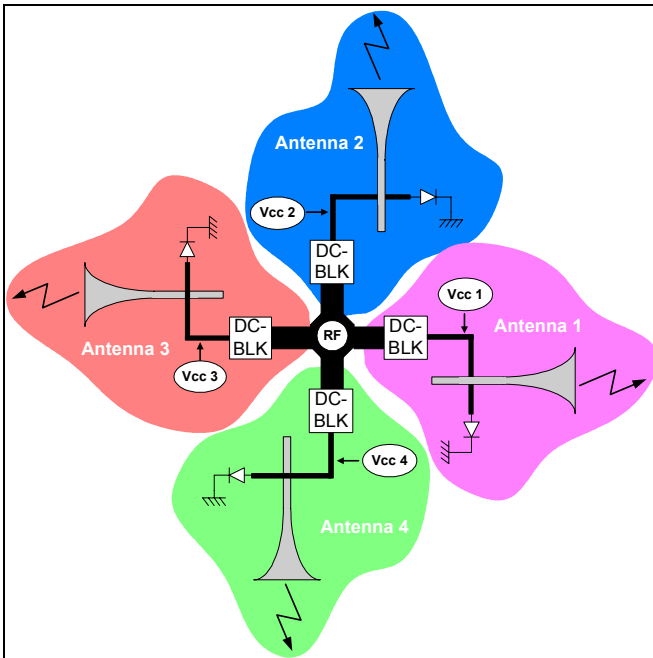


Figure 1: Synoptic of the 4-sector switched beam antenna.

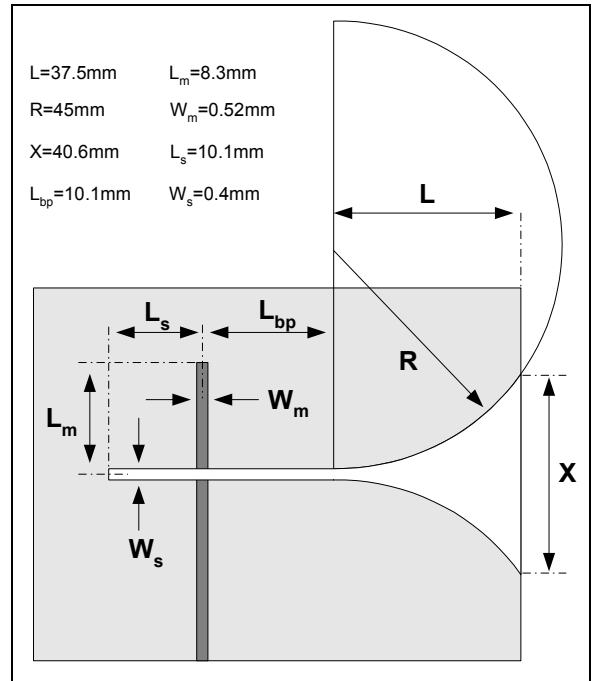


Figure 2: Design of the Vivaldi antenna.

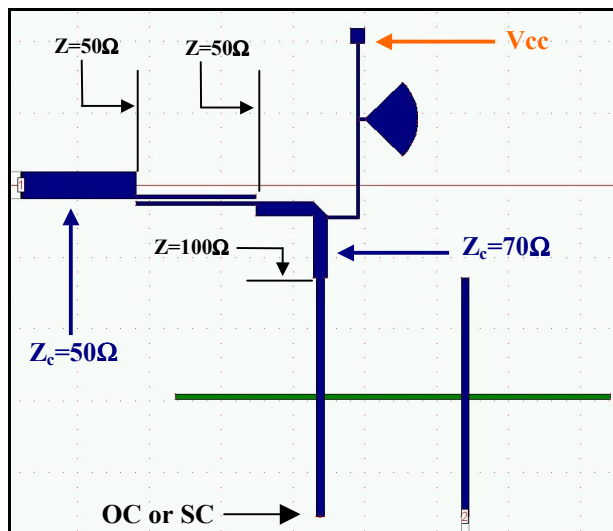


Figure 3: Simulated circuit for the validation of the switch concept.

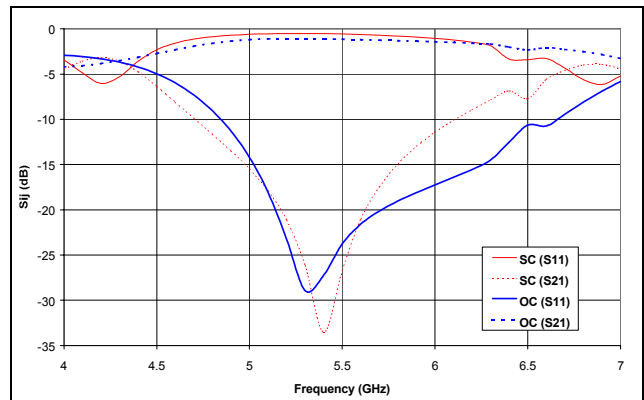


Figure 4: Simulated S-parameters of a single branch switch.

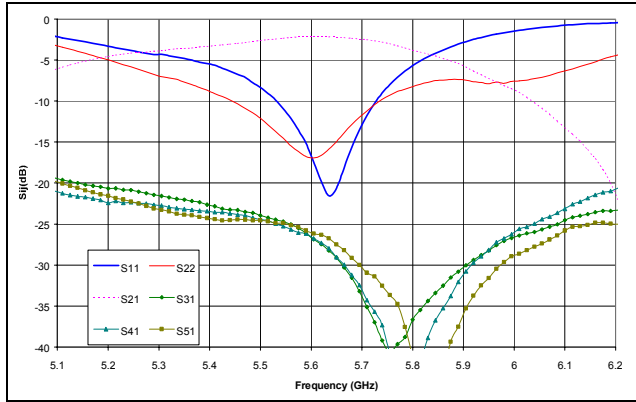


Figure 5: Measured S-parameters of the feeding circuit with ideal diodes.

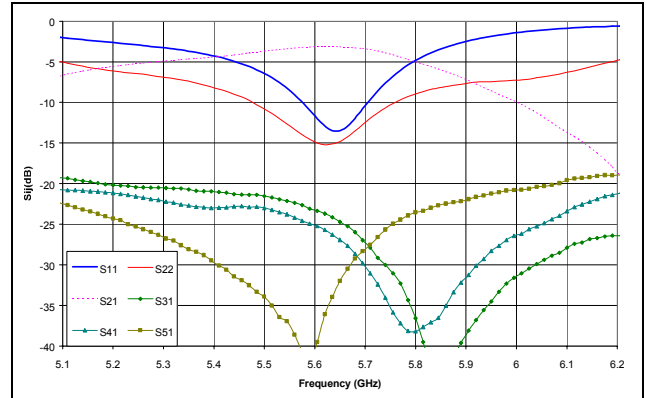


Figure 6: Measured S-parameters of the feeding circuit with real diodes.

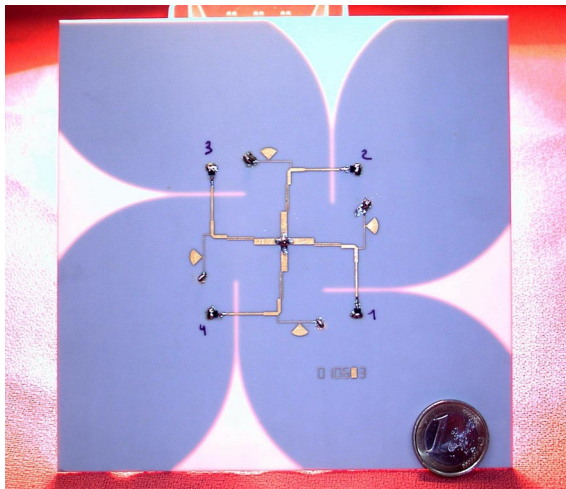


Figure 7: Four-sector switched beam antenna.

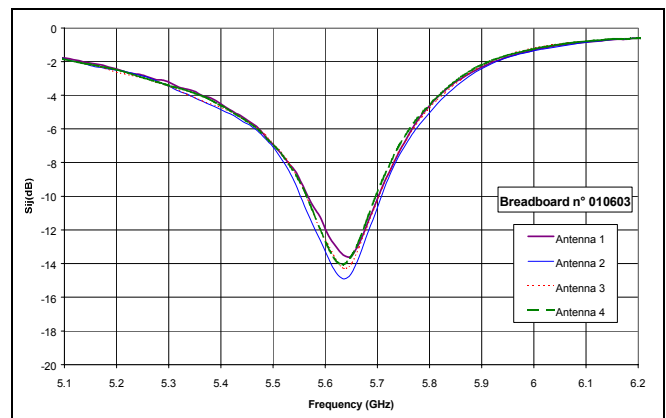


Figure 8: Measured S11 of the four-sector switched beam antenna.

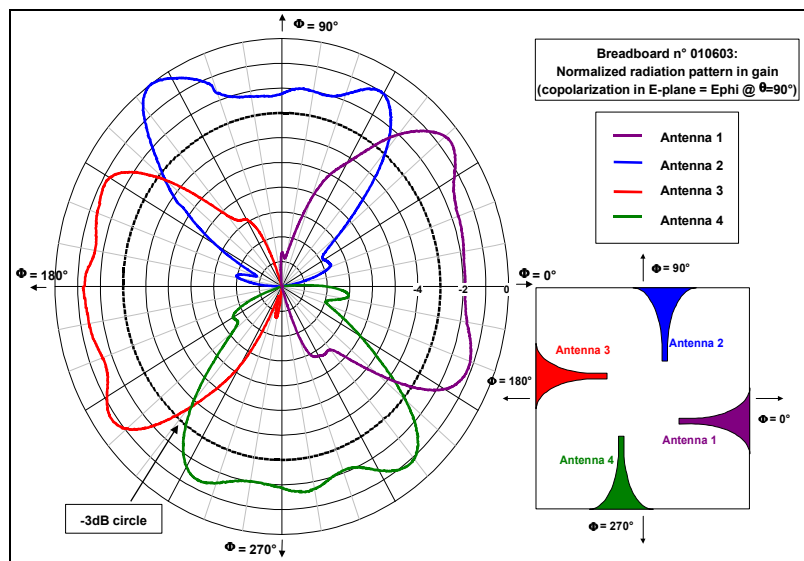


Figure 9: Measured radiation patterns of the four-sector switched beam antenna.