Compact all-metallic cavity-cascaded antenna

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A compact all-metallic cavity-cascaded antenna is presented. A two-end-shorted metallic plate is shorted and divided averagely by five identical shorting walls alternatively, forming five alternatively cascaded open cavities. By selecting proper width of the metallic plate and length of the shorting walls, all the five open cavities operate in the TM_{1n0} ($n = 0.5$) mode, generating five fringing fields with the same phase. Thus, effective radiation is achieved. The proposed antenna is operated in the 5-order mode, e.g. five standing waves are distributed along the proposed antenna. It only occupies a volume of $0.43\lambda_0 \times 2.83\lambda_0$ (λ_0 is the wavelength of the centre frequency). Moreover, the proposed antenna is fabricated by all metal, resulting in low cost, light weight, wide bandwidth, high gain and high efficiency. A prototype that can provide an overlapped impedance bandwidth and 3 dB gain bandwidth of 7.72% from 8.10 to 8.75 GHz and a peak gain of 13.37 dBi at 8.5 GHz is built and measured.

Introduction: Cavity antennas such as metallic cavity antennas and Fabry–Perot (FP) cavity antennas are widely used in telecommunication and radar sensor systems. Two electrically large circular-polarised cavity antennas with an average gain of about 8.5 dBi were proposed for satellite applications in [1, 2]. An ultra-thin dual-band tunable cavity antenna by using the 1-order and 3-order modes is presented in [3]. FP antenna consists of a perfect conductor sheet and a partially reflective surface separating by half wavelength [4]. By using the higher order mode of the resonant cavity, FP antenna can achieve high gain. Some methods have been done to decrease its profile [5–7].

In this Letter, a compact five-segment cavity-cascaded antenna constructed by all metal is proposed. By alternatively shorting the two-end-shorted metallic plate and selecting the proper width of the plate and length of the shorting walls, the five open cavities with the same dimensions are integrated into a whole and each cavity operates in the TM_{1n0} ($n = 0.5$) mode, which is the 5-order mode of the whole antenna. Five fringing fields with the same phase form effective radiation. The all metal antenna has the merits of low cost, light weight and good antenna performance. Furthermore, the proposed antenna only occupies a volume of $0.43\lambda_0 \times 2.83\lambda_0$, which is 44.19% reduction compared with our previous all metal antenna in [8], whose volume is $0.69\lambda_0 \times 3.16\lambda_0$. The peak gain is 13.37 dBi which is slightly higher than 12.47 dBi in [8].

Antenna design: Fig. 1 shows the geometry of the proposed antenna. The five shorting walls divide the two-end-shorted metallic plate into five portions with the same dimension. The width of the metallic plate is 15 mm and the length of each shorting wall is 20 mm. A small via used to connect to the feeding probe has a diameter of 1.3 mm and locates 15.5 mm away from the open edge. Another bigger via used for feeding with a diameter of 4 mm is cut away from the ground plane, which has an optimised dimension of 120 mm × 40 mm.

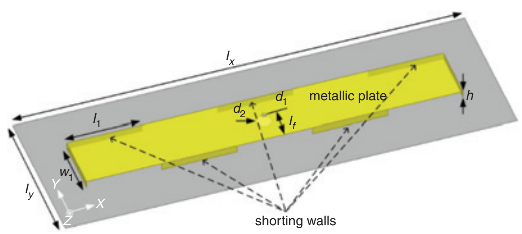

Fig. 1 *Geometry of proposed antenna*

Parameters are: $l_x = 120$, $l_y = 40$, $l_1 = 20$, $w_1 = 15$, $h = 2$, $l_f = 15.5$, $d_1 = 1.3$, $d_2 = 4$, all in millimetre.

Physical mechanism: The complex electric field distribution at the centre frequency of 8.5 GHz is depicted in Fig. 2, which is similar with Fig. 4 *e* in [8]. The five shorting walls averagely divide the plate into five portions, and create some electric nulls together with the other two in the head and tail ends. As can be seen, five standing waves are distributed along the proposed antenna, which is the 5-order mode. Each open resonator cavity is operated in the TM_{1n0} ($n = 0.5$) mode. Cavities 1–3 are TM_{1n0} mode cavities with three side walls open, two of which are virtual shorted circuits and the rest is real open for radiating. Cavities 4–5 are TM_{1n0} mode cavities with two side walls open, one of which is virtual shorted circuit and the other is real open for radiating. Cavity 1 is the active cavity and the energy which is not radiated out flows to the sides, making the rest cavities excited. Since the adjacent open cavities are mirrored with each other and their fields are out-of phase, all the fringing fields have the same phase, resulting in effective radiation.

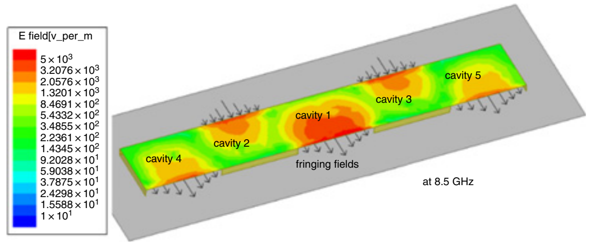

Fig. 2 *Complex electric field distribution at 8.5 GHz and fringing fields which is denoted by black arrow lines for effective radiation*

Results: A prototype of the proposed antenna is shown in Fig. 3, which is fabricated by line-cutting two pieces of 0.5 mm thick copper plates. Commercially available KFDS96-12 SMA is used for feeding. The reflection coefficient is measured by using an Agilent N5247A vector network analyser, and the radiation pattern and gains are obtained in an anechoic chamber.

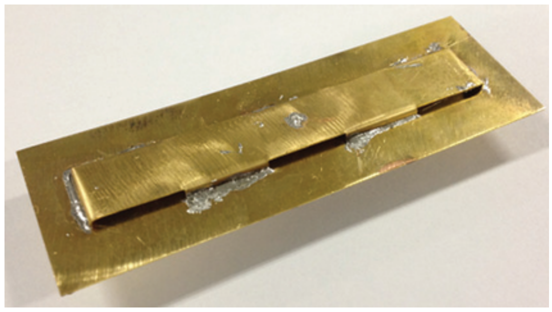

Fig. 3 *Prototype of proposed antenna*

Fig. 4 shows the measured reflection coefficient in comparison with the simulated result in the frequency band from 6 to 9 GHz. Three resonant frequencies are observed, and the former two are the 1-order and 3-order modes as illustrated in Figs. 3, 4*a* and *c* in [8], the first two frequencies cannot form effective radiation at broadside. The 5-order mode around 8.5 GHz is the operating mode we concern. The measured and simulated impedance bandwidths are 7.73–8.73 GHz (1 GHz, 12.15%) and 7.70–8.75 GHz (1.05 GHz, 12.77%), respectively. They agree well with each other.

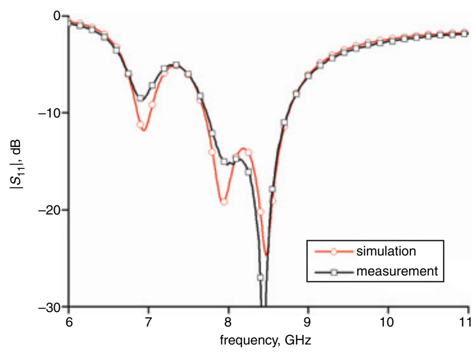

Fig. 4 *Measured and simulated magnitude of reflection coefficients*

Fig. 5 shows the gains at broadside. The simulated gain reaches its maximum of 13.46 dBi at 8.45 GHz, while the measured maximum gain is 13.37 dBi at 8.5 GHz. The simulated and measured 3 dB gain bandwidths in their respective passbands are both 7.72% from 8.10 to 8.75 GHz. The normalised radiation patterns at 8.5 GHz in the

E-plane (*YZ*) and *H*-plane (*XZ*) are presented in Fig. 6. Fan- and pencil-shaped beams are obtained in the *E* and *H* planes, respectively. The maximum measured *x*-pol levels are −22.05 and −21.26 dBi in the *E* and *H* planes, respectively. The measured gains and patterns agree well with the simulation.

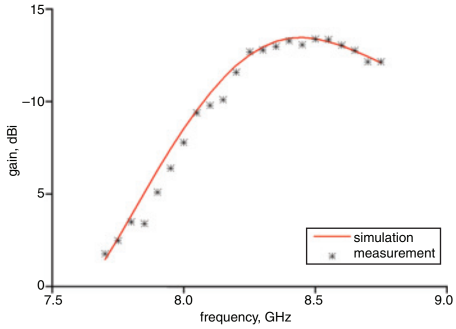

Fig. 5 *Measured and simulated gains at broadside*

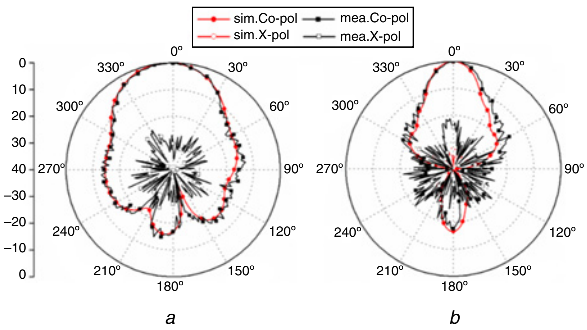

Fig. 6 *Measured and simulated normalised co-pol and x-pol radiation patterns*

a E-plane, *YZ*-plane
b H-plane, *XZ*-plane

Conclusion: A compact all-metallic five-unit cavity-cascaded antenna is introduced in this Letter. The proposed antenna operates in the 5-order mode and each cavity operates in the TM_{1n0} ($n = 0.5$) mode. The all metal structure enables the proposed antenna having good performance. Fan-shaped beam with a gain up to 13.37 dBi and a 3 dB gain bandwidth of 7.72% are achieved.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Zhao, Y., Zhang, Z., and Feng, Z.: ‘An electrically large metallic cavity antenna with circular polarization for satellite applications’, *IEEE Antennas Wirel. Propag. Lett.*, 2011, **10**, pp. 1461–1464
2 Wei, K., Zhang, Z., Zhao, Y., and Feng, Z.: ‘Design of a ring probe-fed metallic cavity antenna for satellite applications’, *IEEE Trans. Antennas Propag.*, 2013, **61**, (9), pp. 4836–4839
3 Trentini, G.V.: ‘Partially reflecting sheet arrays’, *IRE Trans. Antennas Propag.*, 1956, **AP-4**, pp. 666–671
4 Zhao, Y., Zhang, Z., and Feng, Z.: ‘A dual-band tunable ultra-thin cavity antenna’, *IEEE Antennas Wirel. Propag. Lett.*, 2011, **10**, pp. 717–720
5 Feresidis, A., Goussetis, G., Wang, S., and Vardaxoglou, J.: ‘Artificial magnetic conductor surfaces and their application to low-profile high gain planar antennas’, *IEEE Trans. Antennas Propag.*, 2005, **53**, (1), pp. 209–215
6 Sun, Y., Chen, Z., Zhang, Y., Chen, H., and See, T.: ‘Subwavelength substrate-integrated Fabry–Pérot cavity antennas using artificial magnetic conductor’, *IEEE Trans. Antennas Propag.*, 2012, **60**, (1), pp. 30–35
7 Liu, Y., Hao, Y., and Gong, S.: ‘Low-profile high-gain slot antenna with Fabry–Perot cavity and mushroom-like electromagnetic band gap structures’, *Electron. Lett.*, 2015, **51**, (4), pp. 305–306
8 Chang, L., Zhang, Z., Li, Y., and Feng, Z.: ‘All-metal antenna array based on microstrip line structure’, *IEEE Trans. Antennas Propag.*, 2015, **64**, (1), pp. 351–355