Low-cost broadband millimetre-wave array antenna using waveguide/microstrip feed network and slot pair

S.-S. Oh, J. Heo, D.-H. Kim, J.-W. Lee, M.-S. Song and Y.-S. Kim

A low-cost broadband millimetre-wave planar 30 × 30 array antenna is presented. The antenna is fed by a microstrip feed network in the H-plane to decrease fabrication costs, and a waveguide feed network in the E-plane to reduce the feed line loss. The waveguide and microstrip feed network are coupled through the proposed slot pair. The slots are placed one quarter of a guided-wavelength distance apart, so that the reflected waves from the slots cancel each other. A conductive bar is laid above the slots to increase the coupling, which increases the antenna gain by about 1 dBi. The maximum gain is 30.5 dBi at 41.5 GHz. The measured bandwidth is as broad as 7.1%.

Introduction: With the growth of millimetre-wave communications, the demand for a low-cost, broadband, planar array antenna has increased. Although microstrip patch antennas with a microstrip feed network are widely used because of their low fabrication cost, they have large feed line loss and gain degradation in millimetre-wave applications [1]. By contrast, slotted waveguide array antennas have low loss and high efficiency, but high fabrication costs [2]. To obtain both low cost and low loss, waveguide/microstrip feed networks have been reported [3]. However, the arrays fed by these standing-wave feed networks have a very narrow bandwidth and frequency-dependent main beam directions.

In this Letter we present a low-cost 30 × 30 array antenna that has fixed-beams and a broad bandwidth of 40.5–43.5 GHz (7.1%). A waveguide feed network is used in the E-plane direction to reduce feed line loss, and a microstrip feed network is distributed in the H-plane direction to reduce the fabrication cost. The two feed networks are coupled through a centre-inclined slot. To increase coupling, a narrow, thin conductive bar is installed above the slot.

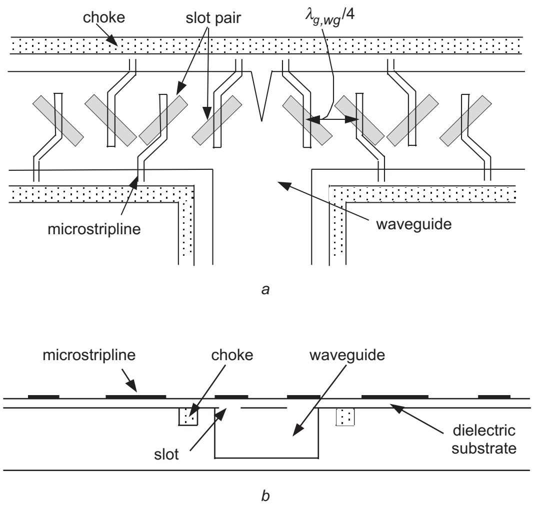

Fig. 1 *Waveguide feed network and slot pair*

a Top view
b Side view

Configuration: A centre-feed travelling-type feed network is adopted to achieve the beam-fixed characteristics, as well as a broad bandwidth [3]. Fig. 1 shows part of the waveguide feed network and slot pairs. The waveguide is milled and placed below the dielectric substrate. The dielectric constant of the substrate is 2.2 and it is 0.254 mm thick. The two ends of a waveguide divided using a T-junction are terminated with an absorber to implement a travelling-type feed network. For sufficient spacing between the antenna elements, the width of the broad wall of the WR-22 waveguide (5.7 mm) at the input port is transited into 4.8 mm, which results in an inter-element spacing of 5.2 mm. To suppress leakage, chokes [2] 2 mm wide and high are grooved along and beside the waveguide, as shown in Fig. 1. These act as short circuits along the upper corner of the waveguide.

If the slots are placed a half guided wavelength of the waveguide apart, the reflected waves from each slot accumulate, and high return loss results. To overcome this inherent characteristic, we propose a waveguide-to-microstrip transition that includes a pair of slots, as shown in Fig. 1. The distance between the two slots is one quarter of a guided wavelength, $\lambda_{g,wg}/4$ (2.65 mm), which offsets the reflected waves from the two slots, resulting in a very low reflection coefficient. From Ansoft's HFSS simulation for one transition, the reflection coefficient of each slot pair is −35 dB, which is smaller than the value of −25 dB for a single slot. As illustrated in Fig. 1, the slot pairs are rotated alternately to achieve in-phase coupling and are spaced 5.2 mm apart. Fifteen slot pairs are placed along each waveguide, for a total of 30 slot pairs. For the −25 dB sidelobe level (SLL), the Chebyshev distribution of the coupled wave along the waveguide feed network was designed. The width of the microstripline and the length and width of the slots were initially set to 0.2, 3.0 and 0.5 mm, respectively, and were adjusted to make the Chebyshev distribution.

Fig. 2 shows part of the microstrip feed network and the 30 patch elements. Since the magnetic field causes slot coupling, the open-ended microstrip line is extended from the slot by one quarter of a guided wavelength of the microstrip line, $\lambda_{g,m}/4$. The microstrip patch element with the parasitic patch near the non-radiating edge described in [4] is adopted as an antenna element. The Zeland IE3D analysis gives a bandwidth of 3.0 GHz (VSWR ≤ 2.1) and well-shaped radiation patterns. The microstrip feed network was designed to have an SLL of −25 dB using the Chebyshev method. The phase of the coupled wave between two slots differs by 90°, as shown in Fig. 2. Therefore, to feed equal phases, the first patch on the left side is $\lambda_{g,m}/4$ more distant than the first on the right side, and the microstrip patch elements are placed in a reverse manner. The central element spacing is 8.3 mm, and the spacing between other adjacent elements is 5.15 mm.

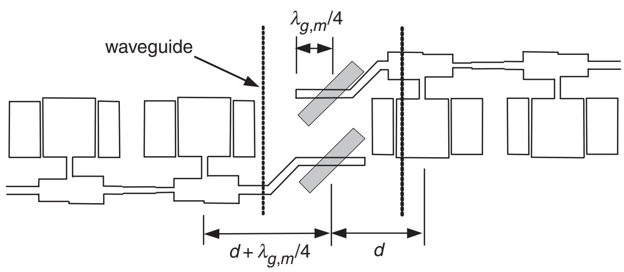

Fig. 2 *Microstrip feed network and patch element*

Measured results: Fig. 3 shows a photograph of a fabricated 30 × 30 array antenna. The grounded, narrow, thin conductive bar is 2.0 mm above the slot pair and fixed to the base plate of the waveguide with screws at both ends, as illustrated in Fig. 2. The bar is 3.0 mm wide and 0.5 mm thick. The conductive bar functions as a reflector that redirects undesirable radiating waves to the microstrip line. The whole patch area is 15.7 × 15.6 cm^2.

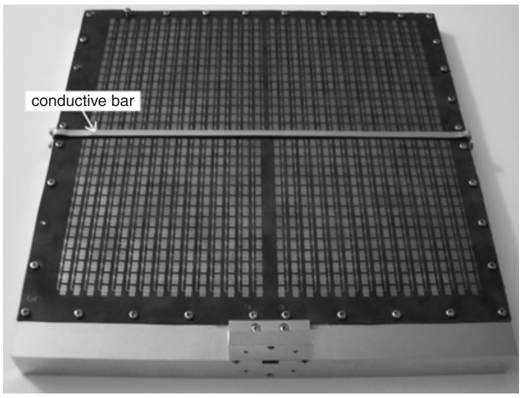

Fig. 3 *Photograph of fabricated 30 × 30 array antenna*

As shown in Fig. 4*a*, the measured return loss has a broad reflection bandwidth over 3 GHz (VSWR ≤ 2.0), which meets the design goal. The measured E-/H-plane radiation patterns are plotted in Fig. 4*b*. The E-plane pattern is asymmetric and the SLL is about −20 dB, although it was designed to be −25 dB. The deterioration might have resulted from the slot alignment, fabrication tolerance, or mutual coupling. The beam widths of the E-/H-plane pattern are 3.0° and 3.5°, respectively. At frequencies distant from the centre frequency, the beam width of the E-/H-plane becomes broad, owing to the centre-feed configuration of the E-/H-plane direction. The measured main beams at all frequencies have a fixed broadside direction because of the centre-feed configuration. The antenna gains for the cases without and with a conductive bar were measured and are plotted in Fig. 5. As expected, the antenna with a conductive bar has a gain about 1 dBi larger than the one without a conductive bar. The maximum gain is 30.5 dBi at 41.5 GHz using the conductive bar.

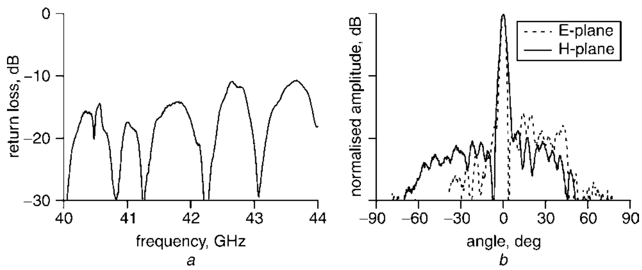

Fig. 4 *Measured results*

a Return loss
b E-/H-plane radiation patterns

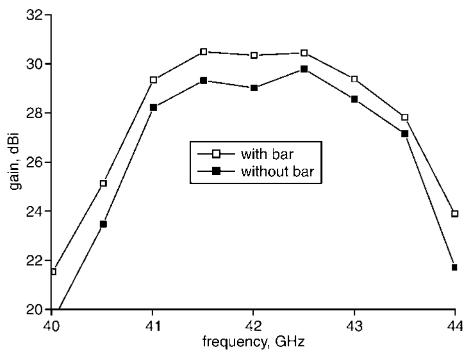

Fig. 5 *Measured antenna gain with and without conductive bar*

Conclusion: A low-cost broadband 30 × 30 millimetre-wave planar array antenna is presented. The antenna was fed using a microstrip and waveguide feed network, which are combined using a proposed slot-to-microstrip transition including slot pairs. The measured reflection bandwidth of the array antenna was as broad as 3.0 GHz. The measured maximum gain was about 30.5 dBi at 41.5 GHz with a conductive bar. The main beam directions are broadside over all frequencies. The proposed antenna array is suitable for broadband millimetre-wave communication services.

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