Fig. 4 shows S_{11} measurements at the hybrid input port with and without the ring matching arrangement, and it can be seen that levels are low and of little significance with regard to RF performance, in both cases.

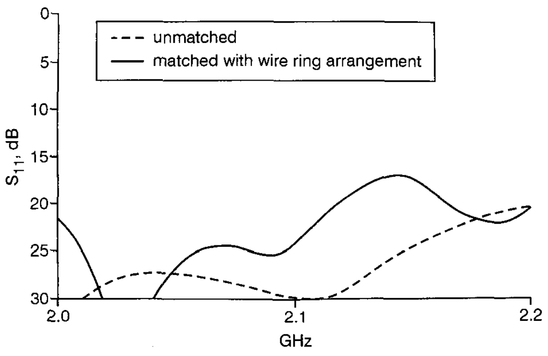

Fig. 4 *S_{11} measurements with quadrifilar helix antenna at feed system hybrid coupler (at 'IN' port)*

On this antenna, the ring arrangement was formed with 0.5 mm diameter tinned copper wires which were soldered to the upper radials on a radius of 11 mm from the antenna axis. The wire spacing was 1.5 mm. The salient dimensions of the ring arrangement, i.e. radius, wire length and spacing, were determined experimentally using the following procedure. In broad terms, the choice of ring radius determines the centre frequency at which impedance matching occurs and is initially optimised; then the wire lengths and spacing are adjusted to achieve minimum return loss.

Concluding remarks: Application of the ring matching arrangement has been investigated experimentally and by numerical modelling for a number of types of quadrifilar helix antenna. These included resonant antennas with three quarter wavelength and one wavelength elements, and two backfire mode antennas with different geometries. Antenna radiation pattern performance is not adversely affected by the addition of a matching ring. Experimental optimisation for a good impedance match is easy to carry out. The ring matching arrangement allows simpler and less bulky feeder systems to be employed with these types of antennas.

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Phase-shifterless beam-steering micro-slotline antenna

Chih-Chiang Chen and Ching-Kuang C. Tzuang

A novel beam-steering leaky-wave antenna that uses reactive loading capacitors along the leaky line is presented. The reactive loading varies the phase constant of the leaky line, altering direction of the main beam. A prototype was constructed and tested, demonstrating that a beam scanning angle of 23° is obtained by periodically loading the 0.06527 pF capacitors along the leaky line at 4 GHz. An electronic beam-steering antenna of scanning angle 13° was established by replacing the MIM capacitors with varactors.

Introduction: Microwave and millimetre-wave radar for wireless communications, imaging and commercial automotive-collision avoidance applications requires low cost, high efficiency, and compact scanning antenna [1]. These characteristics are exhibited by the reactive-loaded antenna, which supports beam control by serially inserting inductors and capacitors into a wire antenna [2] and a microstrip line [3], respectively. This Letter offers a novel approach, capable of incorporating a periodic, capacitor-loaded micro-slotline leaky-wave antenna, as shown in Fig. 1, which produces a steerable beam varied by the external loading capacitance (or inductance).

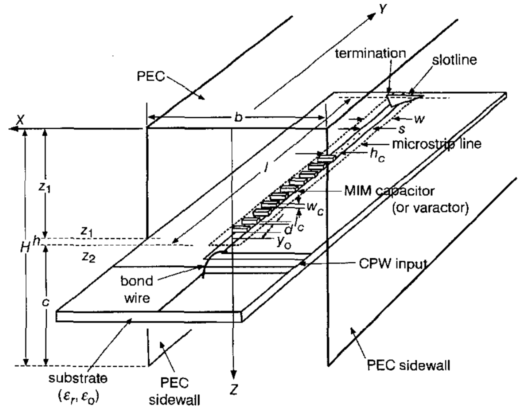

Fig. 1 *Detailed view of beam steering micro-slotline leaky-wave antenna flipped upside down*

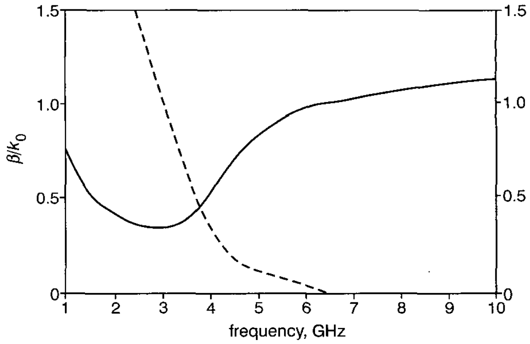

Fig. 2 *Dispersion characteristic of first higher-order EH_1 mode of uniform, unloaded micro-slotline structure*

$w = 1$ mm, $s = 0.4$ mm, $b = 16$ mm, $z_1 = 3$ mm, $h = 0.762$ mm, $\varepsilon_r = 2.55$, $H = \infty$
—— normalised phase constant (β/k_0)
– – – normalised attenuation constant (α/k_0)

Fig. 1 shows the novel beam-controlled antenna flipped upside down for a clearer view; metal-insulator-metal (MIM) capacitors or varactors are placed across the slotline to control the beam. The microstrip is printed on the opposite side of the slotline and governs the radiation of the EH_1 leaky mode. When no reactive loading is present, the structure is reduced to that of the so-called micro-slotline antenna, the dispersion characteristics of which have been thoroughly examined [4]. Fig. 2 describes the complex propagation constants ($\gamma = j\beta + \alpha$) of the first higher-order EH_1 mode by the full-wave integral equation method [4], using the following properly chosen material and structural parameters: $w = 1$ mm, $s = 0.4$ mm, $b = 16$ mm, $z_1 = 3$ mm, $h = 0.762$ mm, $H = \infty$, and $\varepsilon_r = 2.55$. The beam-controlled leaky-wave antenna will be qualitatively discussed, and then the antenna design concept will be validated by comparing the measured and theoretical results.

Antenna design: According to Fig. 1, the input signal propagates along the coplanar waveguide (CPW), and then along the CPW-to-slotline transition, which properly excites the first higher-order EH_1 mode of the micro-slotline [4, 5]. The circuit property of the leaky micro-slotline can be fully modelled by knowing the complex propagation constant and the complex characteristic impedance. The procedure for obtaining the complex characteristic impedance (Z_0) of the leaky line parallels that described by N.K. Das [6]. Accordingly, the equivalent series radiation resistance (R), series inductance (L), shunt radiation conductance (G) and shunt capacitance (C) per unit length, are related to γ and Z_0 of the leaky line by the following expressions:

$$Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)} \tag{1}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta \tag{2}$$

The insertion of capacitors (or varactors) at intervals of d, much less than the free-space wavelength, essentially changes the guiding characteristics by increasing the shunt capacitance per unit length. Thus, the phase constant (β) increases and the magnitude of Z_0 decreases. When β increases, the main beam of the leaky-wave antenna moves toward the horizon (end-fire), at an angle approximated by $\sin^{-1}(\beta/k_0)$, measured from the broadside (z-axis).

A prototype was built using a Rogers ULTRALAM® ULTRA 2000 substrate with $\varepsilon_r = 2.55$ and thickness $h = 0.762$ mm. Fig. 2 shows the structure and material parameters of the leaky-wave antenna, except that the sidewall height is $H = 28$ mm and the antenna length is $l = 220$ mm. MIM capacitors, made of 20 mil (0.508 mm) ARLON CU-CLAD® 250 substrate ($\varepsilon_r = 2.5$) with a surface area of 1 × 1.5 mm, are inserted across the slotline at 2.5 mm intervals. The design includes a total of 79 capacitors.

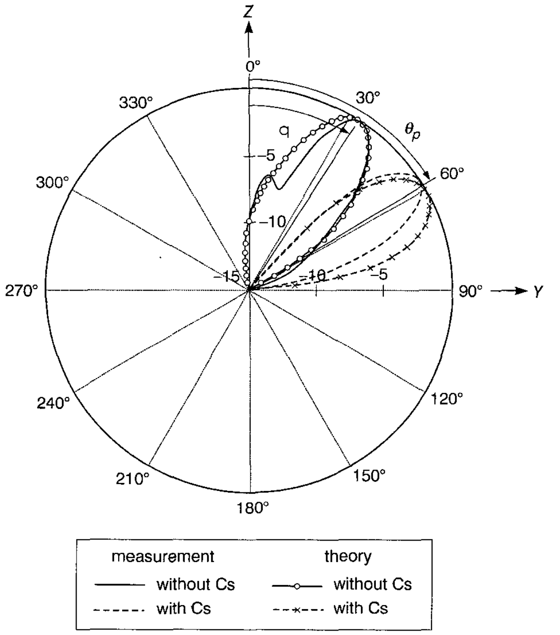

Fig. 3 *H-plane (Y–Z plane) radiation patterns of micro-slotline antenna, without and with capacitors, at $f_0 = 4$ GHz*

Experiments and theoretical verification: An experimental beam steering micro-slotline leaky-wave antenna was fabricated and tested following the theoretical analyses and design outline in the preceding Section. At first, the operational frequency, f_0, is chosen to be in the leaky region ($f_0 < f_{\text{on-set}}$, where $f_{\text{on-set}} = 6.5$ GHz) of the antenna EH_1 mode, as shown in Fig. 2. The measured input reflection coefficients $|S_{11}|$ are approximately −5.27 and −5.81 dB for the unloaded and loaded leaky-wave antenna at $f_0 = 4$ GHz, respectively.

Fig. 3 presents the measured and theoretical radiation H-plane (Y–Z plane) patterns at 4 GHz, with and without the added capacitors. For clarity, only the main beams are depicted. Theoretical calculations were by the normal full-wave three-dimensional integral equation method [7]. Measurements agree closely with theoretical results. The unloaded tilt angle, θ ($\theta \sim \sin^{-1}\beta/k_0$), is 34° (32.5°) for the measured (simulated) radiation pattern. As expected, the loaded tilt angle, θ_p ($\theta_p \sim \sin^{-1}\beta_p/k_0$), is 57° (62.5°) for the measured (simulated) radiation pattern. A beam steering angle of 23° is obtained by merely adding the 0.06527 pF capacitors across the slotline.

An electronic beam-steering control by varying DC voltage is established by replacing the 79 MIM capacitors with four varactor diodes (M/A-COM MA46470, constant Gamma = 1.25). Fig. 4 presents the measured angle of the main beam against DC bias.

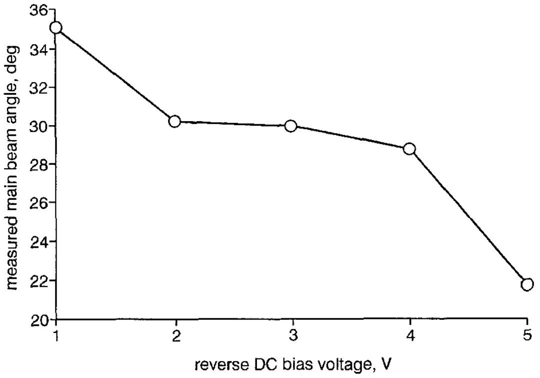

Fig. 4 *Measured main beam angle against reverse DC bias voltage of electronic beam steering micro-slotline leaky-wave antenna, at $f_0 = 3$ GHz*

Conclusions: This Letter presents a robust, beam-steering leaky-wave antenna without a phase shifter. The main beam can be made to point at different angles as desired, by directly manipulating the phase constant of the leaky micro-slotline using the reactive loading across the slotline.

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