A novel dual-wire antenna above a ground plane has been studied for circularly polarised (CP) radiation [1–5]. The antenna has identical elements with a single balanced feed and is characterised by a simple feed system of a two-element array. So far, several elements have been used for the array; they are loop [1–3], spiral-loop [4], and spiral [5].

The purpose of this letter is to propose a novel dual-wire antenna showing wideband CP radiation. For this, we use a curl element [6–8], which is known as a simplified version of a single-arm spiral. The antenna is composed of horizontal curl elements and vertical parallel feedlines above the ground plane and analysed using the moment method [9].

In this letter, we first analyse an antenna with balanced feedlines having two sources. Subsequently, we investigate an antenna with quasi-balanced feedlines having one source [10] to simplify the feed system. Note that the simplified feedlines realise a VSWR of less than 2, which has not been obtained [10]. Also, note that a curl element has been known to have a narrow CP wave bandwidth than a spiral element [11]. However, the present dual curl shows a wider CP wave bandwidth than the dual spiral [5] in the two-element array environment.

Antenna with balanced feedlines: Figure 1 shows the antenna made of wires of the radius $\rho$. The antenna consists of two curl elements at height $h$ above the ground plane. The curl ends $F_{2n}$, $F_{2n}'$ of spacing $S$ and the bottom ends $F_{2n}$ are excited with two sources having the same amplitudes with a phase difference of 180°, as shown in Figure 1(c). To compensate for the phase difference, we rotate the curl element on the $+y$ side by 180° with respect to the other. Note that the curl element is specified by circumference $C$, adjacent wires at distance $d$, and straight segment length $L_s$, as shown in Figure 1(e).

The curl parameters $(C, d, L_s)$ are selected for CP radiation using the moment method [9], where the ground plane size is assumed to be infinite. The curl height is chosen to be the same as that $(h = \lambda_0/4)$ of other dual-wire antennas [1–5], where $\lambda_0$ is the free-space wavelength at a test frequency $f_0$. The feedline spacing and wire radius are $S = 0.025\lambda_0$ [10] and $\rho = \lambda_0/200$ [11].

The simulated axial ratio and gain versus frequency are shown with solid lines in Figure 2. The curl parameters are $(C, d, L_s) = (1.25\lambda_0, 0.052\lambda_0, 0.125\lambda_0)$. It is found that a 3 dB axial-ratio bandwidth is 36%, where the gain is more than 9.3 dBi. For reference, dotted lines show those of an isolated curl element (see the inset) for $(C, d, L_s) = (1.22\lambda_0, 0.046\lambda_0, 0.122\lambda_0)$ at the same height $h$. The bandwidth is 25%, where the gain is more than 6.0 dBi. It can be said that the present antenna’s bandwidth is 1.4 times as wide as that of the isolated element. Note that the curl element’s bandwidth is comparable to that (24%) of a two-wire spiral element at $h = \lambda_0/4$ with a circumference of $1.6\lambda_0$ [11].

Figure 3 shows the simulated radiation patterns at the test frequency $f_0$. The dotted and solid lines show right and left-hand CP wave components, respectively. It is seen that the antenna radiates a left-hand CP beam ($E_y$) in a direction normal to the antenna plane, in the $\pm z$-axis direction. The half-power beamwidths (HPBW’s) are 79° and 57° in the $\phi = 0°$ and 90° planes, respectively. The gain is evaluated to be 9.6 dBi. Note that the principal polarisation ($E_x$) depends on the curl winding direction. In other words, the opposite polarisation ($E_y$) becomes principal one for a curl with a winding direction opposite to that shown in Figure 1.

Antenna with quasi-balanced feedlines: So far, we have analysed an antenna with two sources. In this section, we investigate another antenna with one source to simplify the feed system.

Figure 1(d) shows the simplified feed system with one source. The source excites a bottom end $F_{1'}$ of the feedlines $F_{1}F_{1}'$, and the other end $F_{2'}$ is short-circuited to the ground plane. The short circuit in place of the source is the only difference compared to the antenna in the previous section.

We hold the configuration parameters the same as those in the previous section and analyse the antenna. Solid lines in Figure 4 show the simulated frequency responses of the axial ratio, gain, and VSWR. It is found that the axial-ratio bandwidth is the same as that (36%) for two sources. The gain and VSWR in the bandwidth are more than 8.5 dBi and less than 2, respectively. Note that the VSWR is evaluated based on a 75Ω coaxial line.

The solid and dotted lines in Figure 5 show the simulated radiation patterns at $f_0$. It is found that the antenna radiates a CP beam similar to that for two sources (see Figure 3). The HPBW’s are 80° (79° for two
sources) and 54° (57°) in the φ = 0° and 90° planes, respectively. The gain is 9.3 dBi (9.6 dBi).

Using current distribution, we explain why the radiation characteristics are similar to those for two sources. Figure 6(a–d) show the currents for one and two sources, respectively. A comparison between the currents reveals that the antenna for one source has a traveling-wave tape current distribution, similar to that for two sources. The amplitude decreases from curl end $F_x$ toward the centre $o_x$, and the phase varies almost linearly along the arm length. It is also observed that the currents along feedlines $F_x$–$F_x$ for one source have almost the same amplitudes with a phase difference of 180° as the corresponding currents for two sources. In summary, the similar radiation characteristics for one source are attributed to induced currents appropriate for CP radiation.

To validate the simulated results, we perform experiments. An antenna is fabricated at $f_0 = 3$ GHz using the ground plane of $5\lambda_0 \times 5\lambda_0$. 

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**Fig. 3** Simulated radiation patterns for balanced feedlines. (a) $\phi = 0^\circ$ plane, (b) $\phi = 90^\circ$ plane

**Fig. 4** Frequency responses for quasi-balanced feedlines. (a) Axial ratio and gain, (b) VSWR

**Fig. 5** Radiation patterns for quasi-balanced feedlines. (a) $\phi = 0^\circ$ plane, (b) $\phi = 90^\circ$ plane

**Fig. 6** Current distributions. (a) Curl with a quasi-balanced feedline on the $+y$ side, (b) curl with a quasi-balanced feedline on the $-y$ side, (c) curl with a balanced feedline on the $+y$ side, (d) curl with a balanced feedline on the $-y$ side
Table 1. Comparisons between the present and similar studies

| Radiation element | Loop | AR < 3 dB bandwidth (%) | [1] | [2] | [3] | Spiral-loop [4] | Spiral [5] | Curl (present) |
|-------------------|------|-------------------------|-----|-----|-----|----------------|------------|----------------|
|                   |      | AR (axial ratio), GL (gap loading), PE (parasitic element), SR (sequential rotation), TE (traveling-wave type element), – (not described), RL (return loss) |
| Wideband technique| GL   | GL & PE                 |     |     |     | TE             | TE         | TE             |
| Feed network      | Coaxial line | Microstrip line | Tapered line | Microstrip line | – | Parallel lines |
| Operating frequency (GHz) | 1.5 | 6 | 3 | 1.5 | 2.5 | 3 |
| Gain (dBi)        | 9.75 | 10 | 10 | 9.25 | 10 | 10 |
| VSWR < 2 bandwidth (%) | 22 | (38) VSWR < 1.8 | 29 | (6.7) RL < 10 dB | – | 36 |

Fig. 7 Photographs of a prototype with quasi-balanced feedlines. (a) Top view, (b) side view

Figure 7 shows the antenna photographs. The experimental results are shown with dots and small circles in Figures 4 and 5. They agree with the simulated results.

Finally, we compare our results with those of other dual-wire antennas. The comparisons are summarised in Table 1. It is emphasized that the present antenna has the widest CP wave bandwidth. The bandwidth is 1.4 times as wide as that of a dual-spiral antenna [5]. Note that the spiral arm is closely wound with more turns than the curl.

Conclusion: A curl antenna has been used in a two-element array at the height of $\lambda_0/4$ above the ground plane. It is found that the isolated element has a 3 dB axial-ratio bandwidth of 25%, which is comparable to that of a spiral element at the same height with a circumference of less than $2\lambda_0$. It is also found that the bandwidth further increases to 36% in a two-element array with balanced feedlines having two sources. We reveal that quasi-balanced feedlines having one source lead to a VSWR of less than two, not deteriorating the axial-ratio bandwidth.

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