A Small Steerable-Beam Antenna

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Abstract

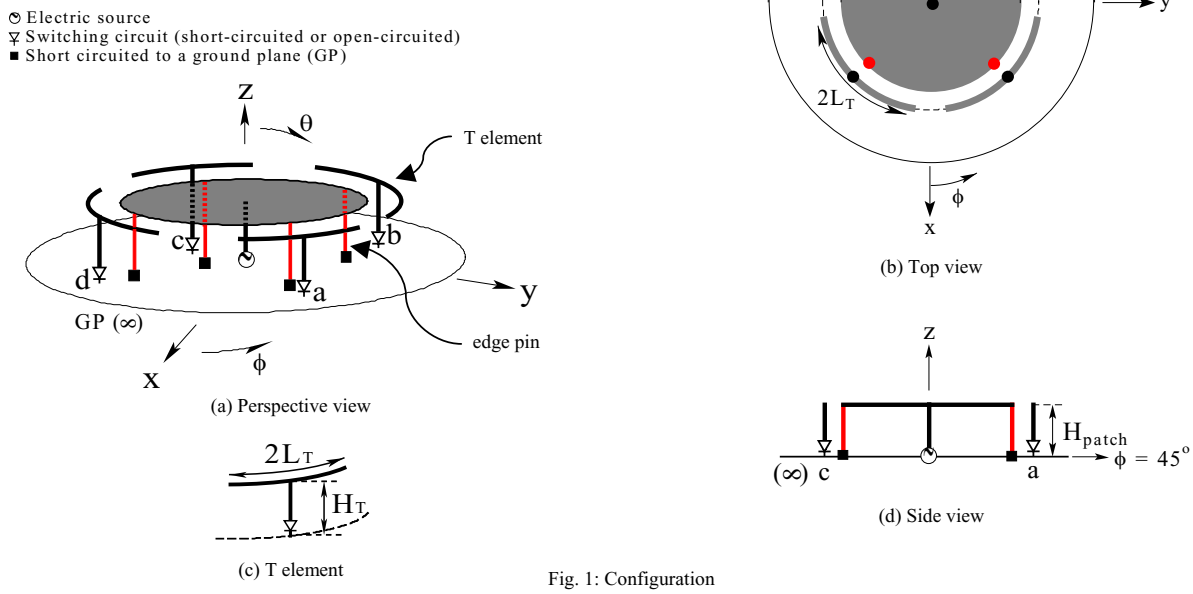
A round driven patch surrounded by four parasitic T elements is investigated to realize a steerable beam. The steered beam is obtained by selecting the connection state of the T elements (either open-circuited or short-circuited) to the ground plane. Eight connection states for the T elements are analyzed. It is found that the radiation beam is steerable in eight azimuthal directions (ϕ = 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). The VSWR is less than 2 for all eight states. The directivity in the maximum beam direction is approximately 8 dB.

1. Introduction

An antenna whose beam direction can be controlled (a steerable-beam antenna) has been attracting attention in response to recent developments in mobile communication systems [1]-[5]. The antenna in [1], composed of one driven square patch and four square parasitic patches, is one such antenna, where the five patches are linearly arrayed on the x-axis. The beam from this patch array is steered in the + x direction and – x direction by shorting the parasitic patches to the ground plane. Each side length of these five patches is approximately 0.23 wavelength, and hence the total length of the array on the x-axis, including the spacing between neighbouring patches, exceeds 1.15 wavelengths (5 × 0.23 wavelengths + spacing).

The antenna in [5] is an extended version of the x-linear array in [1], with one driven patch (located at the coordinate origin) surrounded by four parasitic patches. Two of these four parasitic elements are arrayed in the x-axis and the remaining two are arrayed in the y-axis, that is, the parasitic patches are arrayed in a cross. The beam is steered in the ± x-directions and ± y-directions by shorting the parasitic patches to the ground plane. The antenna occupies an area of approximately 0.94 wavelength × 1.18 wavelengths.

This paper presents a novel steerable-beam antenna that is smaller than the abovementioned two antennas [1][5]. This novel antenna occupies an area of less than 0.3 wavelength × 0.3 wavelength. The antenna is composed of a driven element (a circular patch) and four T-figured parasitic elements, which surround the driven element, as shown in Fig. 1. The antenna is designed to steer the beam in eight azimuthal directions (ϕ = 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). The input impedance and directivity are also presented and discussed.



(a) Perspective view

(b) Top view

(c) T element

(d) Side view

Fig. 1: Configuration

TABLE 1: PARAMETERS

	symbol	value
wavelength	λ_3	10 cm
patch diameter	D_{patch}	$0.24\lambda_3$
patch height	H_{patch}	$0.08\lambda_3$
T element height	H_T	$0.08\lambda_3$
T horizontal length	$2L_T$	$0.196\lambda_3$
number of T elements	N_T	4
number of edge pins	N_{pin}	4
ground plane diameter	D_{GP}	infinite

TABLE 2: SWITCHING STATES

	A	b	c	d
State 1	S	O	O	S
State 2	S	O	O	O
State 3	S	S	O	O
State 4	O	S	O	O
State 5	O	S	S	O
State 6	O	O	S	O
State 7	O	O	S	S
State 8	O	O	O	S

2. CONFIGURATION

Fig. 1 shows the antenna to be considered in this paper. The central patch is driven by the inner conductor of a coaxial line. The outer conductor is connected to the ground plane. T-figured elements (simply called T elements) surround the central patch. The bottom end of each T element is either short-circuited or open-circuited to the ground plane. The main antenna parameters are as follows: patch diameter D_{patch}, patch height H_{patch}, T element height H_T, T horizontal length $2L_T$, number of T elements N_T, number of edge pins N_{pin}, and ground plane diameter D_{GP}. The values for these parameters are shown in Table 1, where λ_3 is the free space wavelength at 3 GHz.

3. ANALYSIS AND DISCUSSION

Table 2 illustrates the state of each T-element (switching state). The symbols "o" and "s" indicate whether the bottom end of the T element is open-circuited or short-circuited to the ground plane, respectively. For odd-numbered switching states, the number of shorted T elements is two, while, for even-numbered switching states, the number of shorted T elements is one.

The antenna characteristics for these switching states are analyzed using the FDTD method [6]-[8]. The radiation field (having E_θ and E_ϕ components) is calculated using the electric and magnetic fields on a surface enclosing the antenna [9]. The input current (I_{in}), which is used for calculating the input impedance ($Z_{in} = R_{in} + jX_{in}$) and subsequently the VSWR, is obtained by integrating the magnetic field around the input terminals. Based on E_θ, E_ϕ, I_{in}, and R_{in}, the directivity is calculated.

Fig. 2 shows the beam direction (θ_{max}, ϕ_{max}) for the eight switching states. It is found that ϕ_{max} changes in 45-degree increments from state to state. In other words, the azimuth angle ϕ_{max} can be controlled by selecting the appropriate switching state. Fig. 2 also shows that θ_{max} is constant irrespective of the switching state.

Fig. 3 shows representative radiation patterns in two planes: the x-y plane and the x'-z plane, where the x'-z plane is at an azimuth angle ϕ_{max} relative to the x-axis. It is found that the co-polarization component is E_θ, which is generated from the vertical currents along the vertical central driven pin, edge pins, and parasitic T element pins. As desired, the cross-polarization component is less than -30 dB.

The VSWRs for the eight switching states show values of less than 2. Since the radiation pattern and input impedance do not vary remarkably for the eight switching states, variation in the directivity is expected to be small. This is confirmed in Fig. 4, where the directivity shows an almost constant value of approximately 8 dB for all eight states.

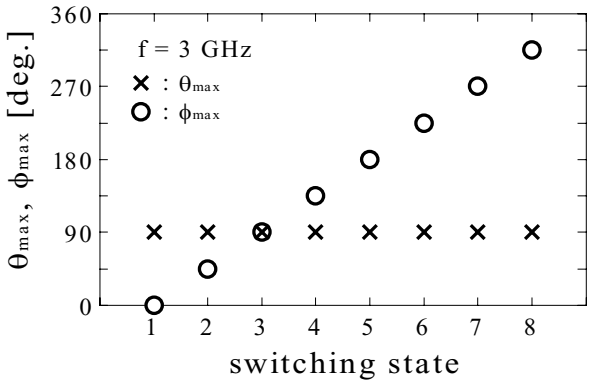


Fig.2: The beam direction versus switching state

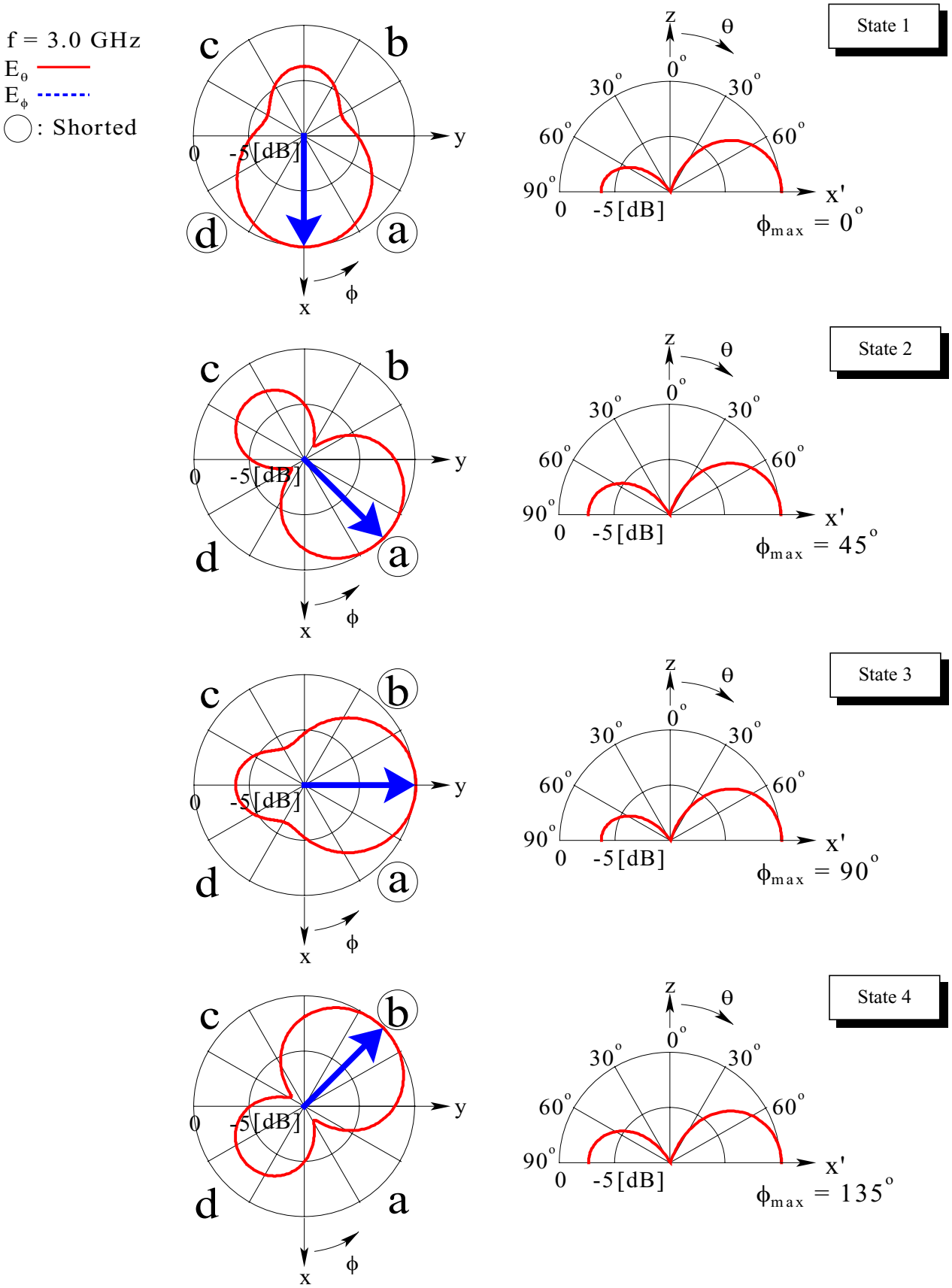


Fig.3: Radiation patterns

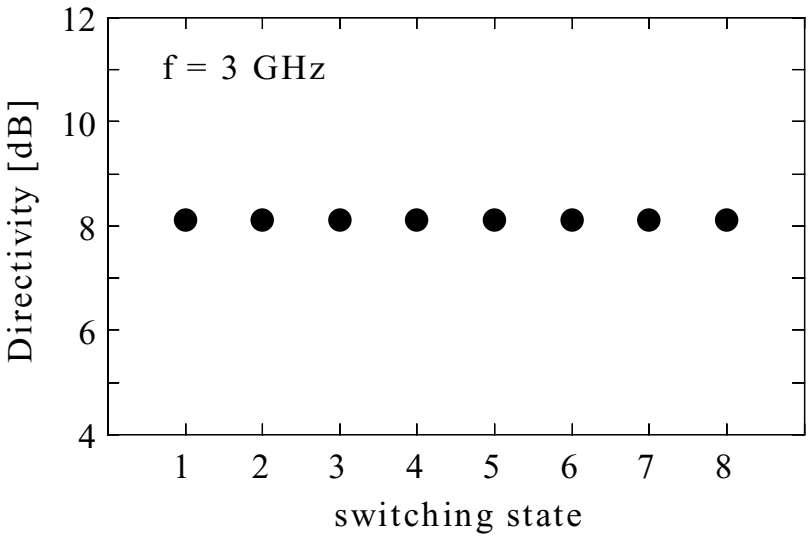


Fig.4: Directivity in the beam direction

4. Conclusions

A steerable-beam antenna composed of a driven circular patch surrounded by parasitic T elements is presented. The direction of the radiation beam is controlled by selecting the state of the bottom end of the T element (either open-circuited or short-circuited to the ground plane). The analysis is performed using the FDTD method. It is found that the antenna can steer the beam in the directions $\phi = 0°$, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The directivity is approximately 8 dB. An advantage of this antenna is that it is smaller than conventional steerable-beam antennas.

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