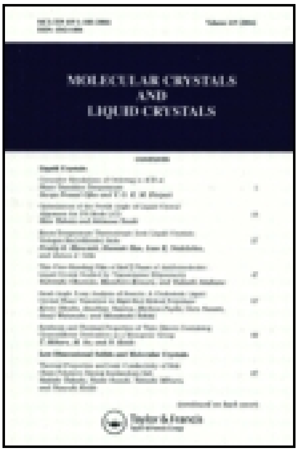

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A novel phase shifter loaded with LC for operation in the microwave band has been proposed and its application to array antenna is demonstrated experimentally. The phase shifting operation is based on the anisotropy of dielectric permittivity of the liquid crystal caused by the change of applied electric field. As an application of such LC loaded phase shifter, we utilized the phase shifter as a means for electrically controlling the phase of microwave signal fed to a two-element array antenna comprised of two microstrip antennas that was designed for operating at 20-GHz-band. We have confirmed that the radiation directivity of the array antenna can be controlled by the applied bias voltage.

Keywords Directivity; Liquid crystals loaded phase shifter with CPW-FE; microstrip antenna; microwave; two elements array

1. Introduction

Microwave tunable components such as phase shifters and filters have attracted considerable attention for satellite broadcast application. Nematic liquid crystal (NLC) is found to be useful in realizing such microwave phase shifters [1–4]. Operation of these phase shifters is based on controlling the orientation of LC's anisotropy of dielectric permittivity with an applied electric field, which allows for external control of the phase of microwave signal. It is well known that when the relative phases of the feeding RF signals to the array antenna are changed, the direction of a main beam can be controlled [5]. Thus in our experiment, a liquid crystal (LC) loaded phase shifter which we had fabricated is used to control electrically the phase of the feeding RF signal. In this paper, we report operating characteristics of two element microstrip array antenna with LC loaded coplanar waveguide with floating electrode (CPW-FE) phase shifter suitable for next generation broadcasting satellite applications.

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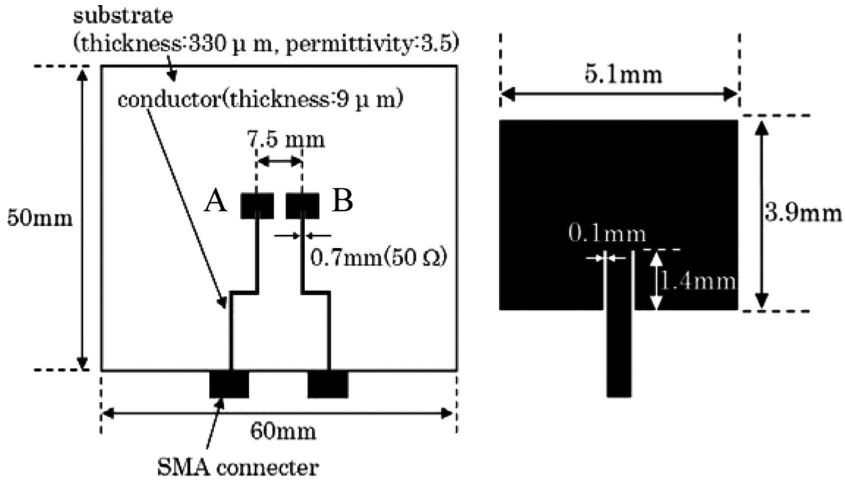

Figure 1. Two element microstrip array antenna.

2. Two Element Microstrip Array Antenna

Figure 1 shows the top view of the two elements (A and B) microstrip array patch antenna (left side figure) and the close-up view of the microstrip antenna element (right side figure). The LC loaded phase shifter was connected to the feeding power point (SMA connector) of the array antenna shown in Figure 1, and the phase of the RF signal was controlled by the bias voltage applied to the LC Layer.

The microstrip antenna and the power feeder were designed for operating at 20 GH and were fabricated by chemical etching on one side of the double sided copper-lined substrate (50 mm × 60 mm, dielectric permittivity = 3.5, substrate thickness = 330 μm, and conductor thickness = 9 μm). The RF signal to the antenna was supplied through the SMA connector mounted on the edge of microstrip line (MSL).

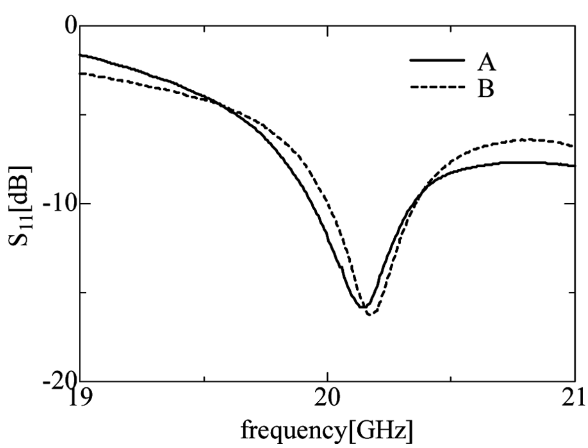

Figure 2. Reflection property of each antenna element (S_{11}).

Figure 2 shows the measured reflection property (S_{11}) of each antenna element (A, B). From this figure, the operating frequencies of these antennas (A, B) were measured around 20.2 GHz, and the value was very close to the designed operation frequency.

3. LC Loaded CPW-FE Phase Shifter

External and cross-sectional views of the LC loaded CPW-FE variable phase shifter, and meander line coplanar waveguide are shown in Figure 3. The meander line CPW was fabricated on a microwave substrate with a 330-μm-thick dielectric layer (relative permittivity: 3.5) and 9-μm-thick metallic layer of copper. The center conductor width was 300 μm, the gap between the center conductor and the ground plane was 100 μm, and the ground plane width was 1600 μm. The upper part of the CPW consisted of a 23 mm × 19 mm × 100 μm floating electrode, which was positioned parallel to the CPW substrate using 250 μm-thick spacers. The space between the electrode and the CPW was filled with a NLC (BL006, Merck). Note that no particular

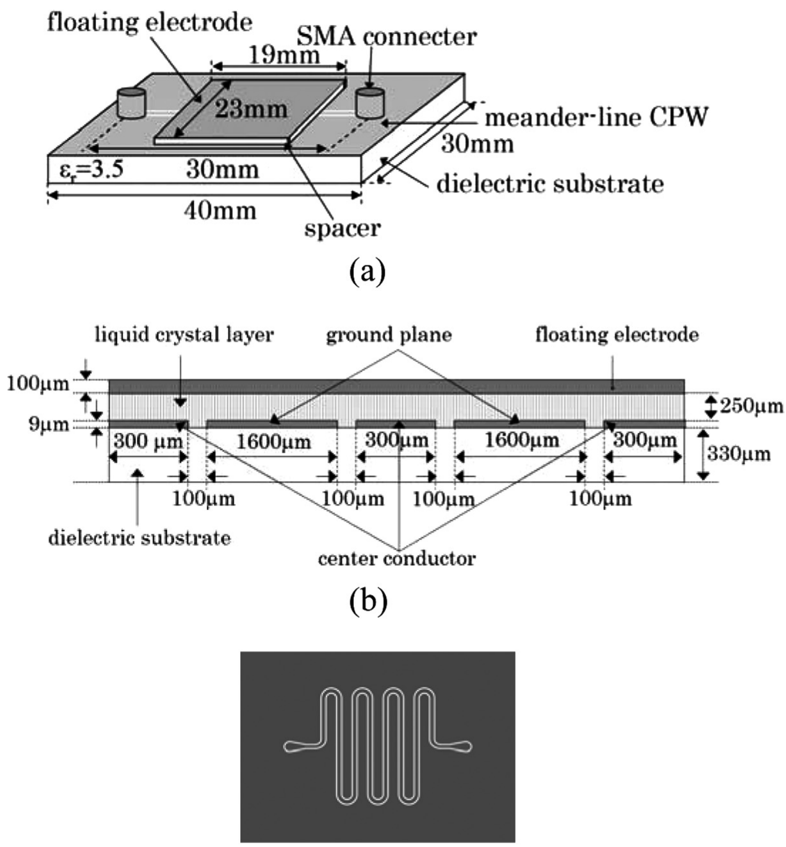

Figure 3. Structure of LC loaded variable phase shifter using CPW-FE: (a) perspective view; (b) cross-sectional view, and (c) meander line coplanar waveguide.

orientation process (such as rubbing) was performed on the floating electrode and CPW substrate surfaces. Length (L) of the meander line CPW under the floating electrode was 142 mm, and the SMA connectors were vertically installed on the substrate at both ends of CPW [6].

Figure 4 shows LC molecule orientations, bias electric field, and radio-frequency electric field under two different bias conditions. In figure 4(a), the bias voltage was applied to the center conductor while the floating electrode was disconnected from the ground plane. In this case, the bias field was almost horizontal (named as "H state"). In figure 4(b), the bias voltage was applied to the floating electrode while the center conductor was grounded. In this case, the bias field was almost perpendicular (named as "P state"). Thus switching between these "H state" and "P state", resulted in a change in the orientation of the LC molecules, which caused the microwave signal passing through the CPW-FE experience different dielectric permittivity and phase shift.

In Figure 4(a), the bias field in the LC layer is mostly the same as the CPW radio-frequency electric field, so that the radio-frequency electric field experiences

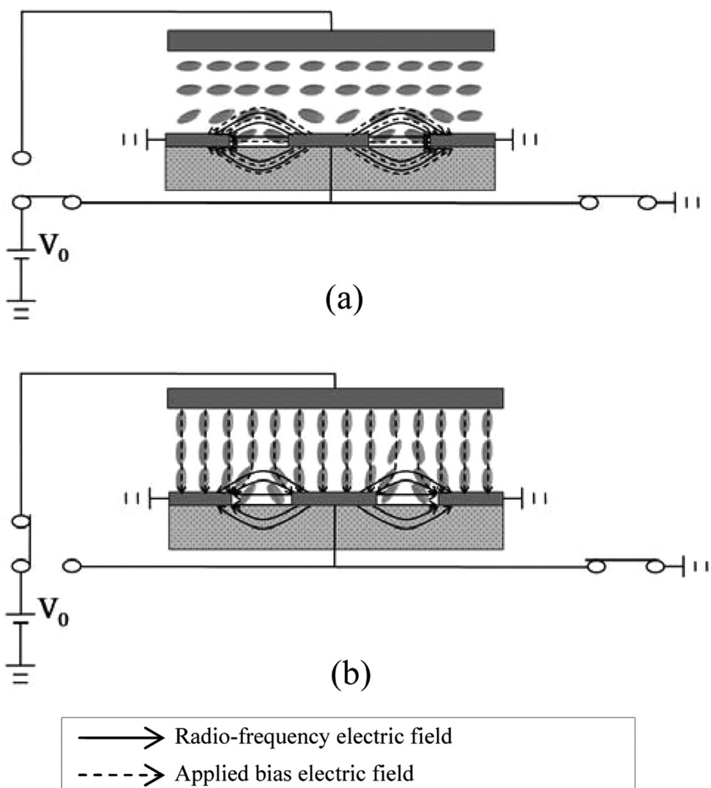

Figure 4. LC molecular orientations, bias electric field and radio-frequency electric field under two different bias states: (a) when a voltage is applied to the center conductor; (b) when a voltage is applied to the floating electrode.

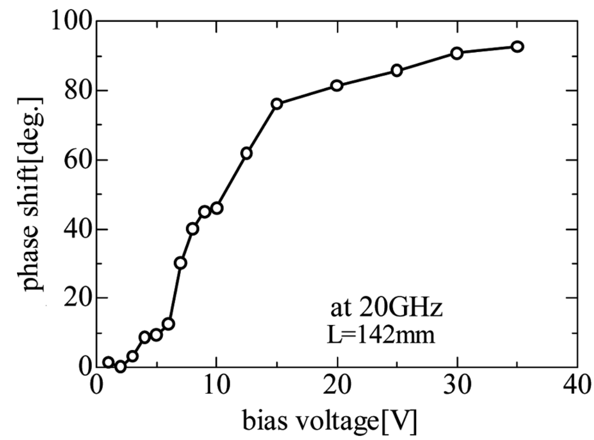

Figure 5. Measured phase shift as a function of bias voltage.

the permittivity along the director n ($\varepsilon_{||}$) between the center electrode and the ground plane. Conversely, in Figure 4(b), the LC driving bias electrical field is applied between the floating electrode and the CPW center conductor and ground plane, so the director n tend to align with the electric field. Thus the radio-frequency electric field feels the permittivity perpendicular to the director n ($\varepsilon_{\perp}$). In other words, by changing the direction of the applied bias voltage (changing the "H state" and "P state"), the orientation of the LC molecules between the center electrode and the ground plane can be changed to either perpendicular or horizontal to the direction of radio-frequency electric field in the area. Since the electric field intensity is high in the CPW region, a change of permittivity affects the phase of high frequency electric field considerably. In our experiments, we switched these bias states by using a control circuit with external relay switches.

Figure 5 shows the measured phase shift of the LC loaded phase shifter as a function of bias voltage. The amount of the phase shift increases in proportion to

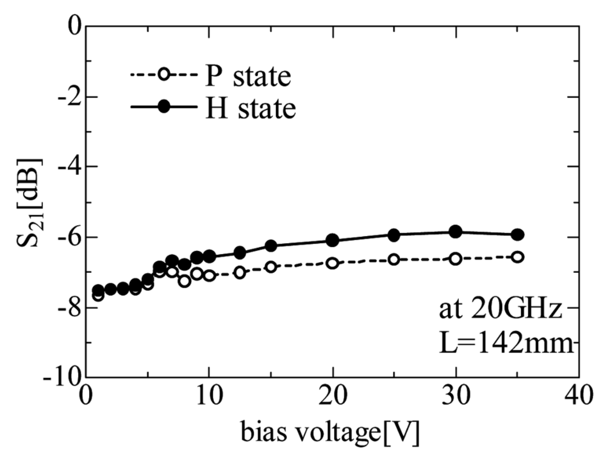

Figure 6. Measured transmission loss (S_{21}) as a function of bias voltage.

an increase of the bias voltage, and when the bias voltage is increased more than 30 V, the phase shift reaches around 90 degrees.

Figure 6 shows the measured transmission loss (S_{21}) as a function of bias voltage for the two bias states P and H. As shown in the figure, the measured transmission loss of phase shifter changes between −6 and −8 dB, and the transmission losses decrease as the applied bias voltage increases.

4. Characterization of Two Element Microstrip Array Antennas Employing a LC Loaded CPW-FE Phase Shifter

The array antenna can change its directivity of radiation by changing the relative phase of the feeding signal to each antenna. In this section, we examine the controllability of a main beam direction in the two element microstrip array antenna by changing the phase of the feeding signal to the antenna using a LC loaded CPW-FE phase shifter.

Figure 7 shows the antenna measurement setup. The 20.2 GHz RF-signal generated by a signal generator (Anritsu 68067C) was amplified with the high frequency amplifier and was radiated using a standard horn antenna (ARH-4223-02, Ducommun Technologies). An attenuator (−10 dB) and the phase shifter (Anritsu A5N1001) were inserted between antenna A and the divider. The purpose of the phase shifter was to adjust the initial phase, and that of the attenuator was to adjust the total loss of each transmission lines between the divider and two element microstrip antennas A and B.

A bias T circuit and the LC loaded CPW-FE phase shifter were inserted between antenna B and the divider. A square wave signal at a repetition rate of 5 kHz

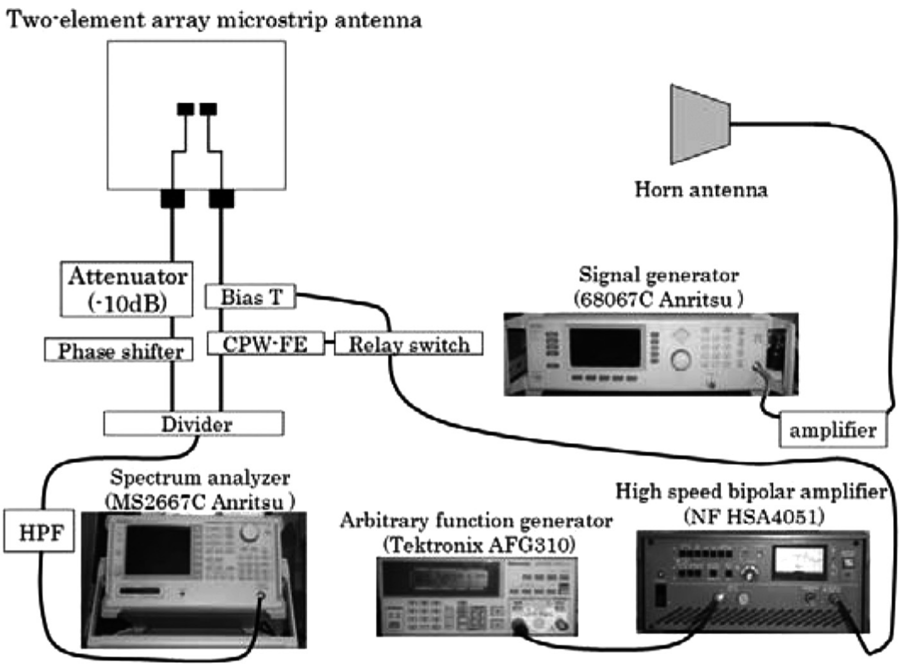

Figure 7. Experimental setup.

generated by a function generator (Tektronix AFG310) and amplified by a bipolar amplifier (NF HSA4051) and a DC voltage to control the phase shift were applied to the center conductor (or FE of CPW) through the relay switch. The bias T circuit was used to superimpose the above bias signal (AC of 5 kHz square wave) on RF signal in case of Figure 4(a). A high-pass filter (Waka Corp.) is inserted between the divider and a spectrum analyzer (Anritsu MS2667C) to protect the measuring instrument from the bias signal component.

Figure 8 shows the measured radiation patterns of the two element array antenna. Figure 8(a) and (b) show the radiation pattern measured in the y-z plane (H-plane) and the x-y plane (E-plane), respectively. In these figures, black dots correspond to the measured results in "H state" as shown in Figure 4(a), and the gray dots correspond to those in "P state" as shown in Figure 4(b). For an applied bias voltage of 30 V, the phase shift was around 90 degrees. Please note that each radiation pattern in the figures is normalized by its peak value. As shown in Figure 8(a), by changing the bias condition from "P state" to "H state", a beam- tilt of 26 degrees was obtained in the y-z plane. On the other hand, in the x-y plane

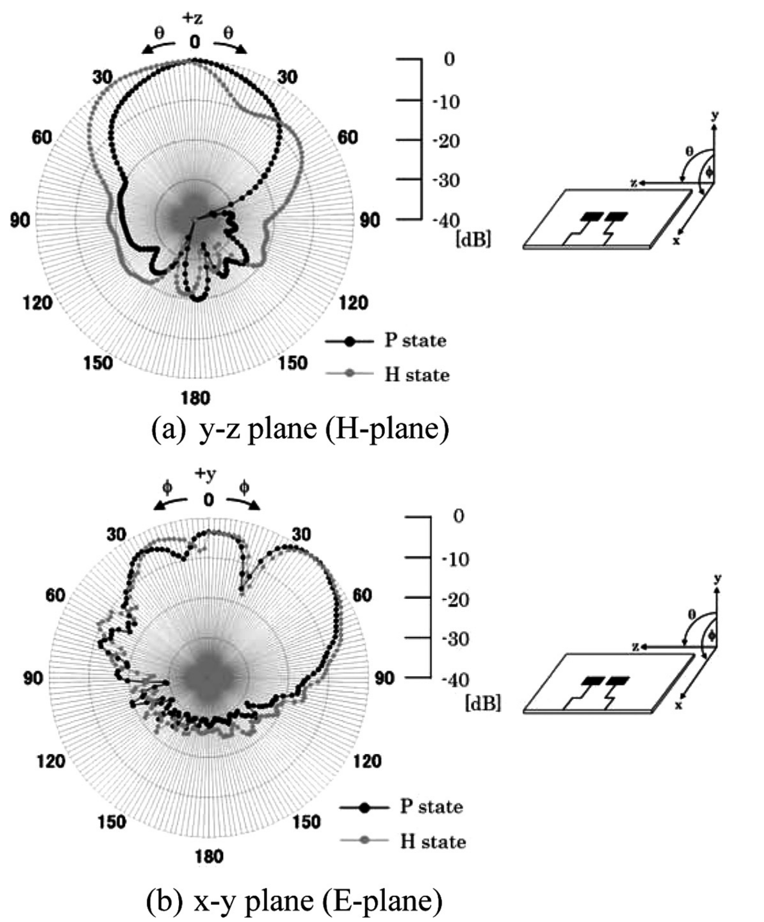

Figure 8. Directivity change of two element microstrip array antenna that uses LC loaded CPW-FE phase shifter.

(as shown in Figure 8(b)), the radiation patterns indicated with black and gray dots remained almost unchanged under the two different bias conditions, and their radiation pattern peaked at 45 degrees for both cases. These characteristics might be attributed to the current design of the array antenna. Since the microstrip lines with kink structure was used as power feeder lines, these may feel the RF signal from the horn antenna, and this effect may result in distortion of the radiation patterns shown in Figure 4(b).

Figure 9(a) and (b) show the simulated radiation patterns of the array antenna using a electromagnetic field simulator MW Studio (CST Corp.). By comparing these results with Figure 8(a) and (b), the simulated patterns and the experimentally measured patterns show almost similar tendency except the small variations appeared in experimental results caused by the fabrication process and our measurement environment. From Figure 9(a), the beam tilt of 30 degrees is obtained by the

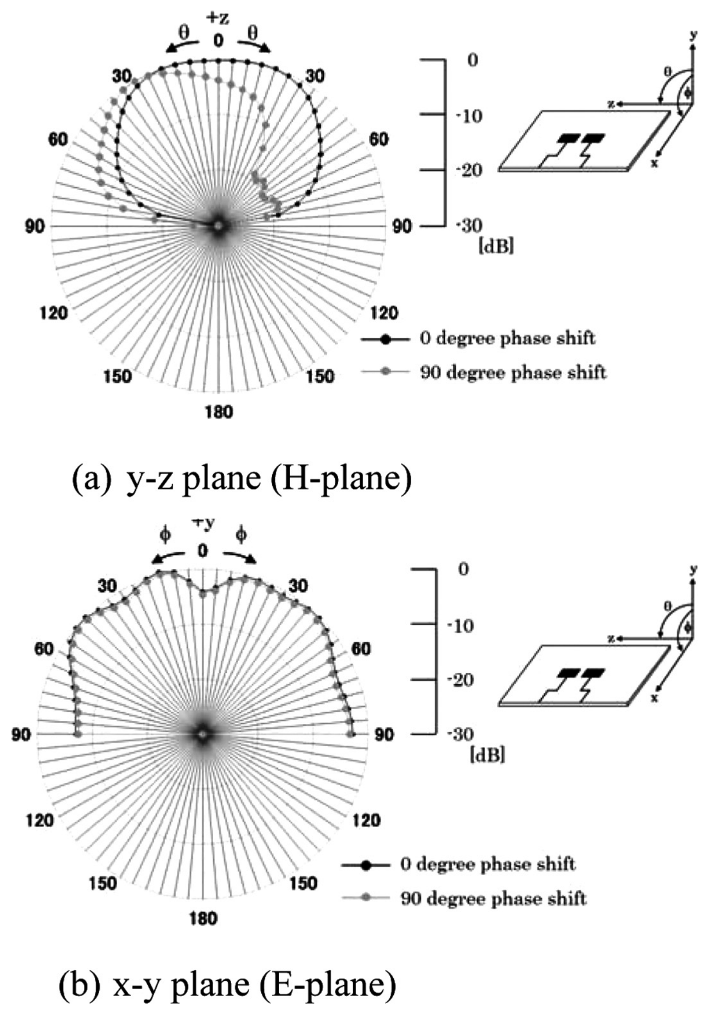

Figure 9. Simulated radiation pattern showing directivity change of the two-element microstrip array antenna under application of phase shift.

phase shift of 90 degrees. Difference between the simulated and experimentally obtained tilt angle is only 4 degrees, and there may be two reasons that cause the small difference. The one reason is that the actual phase shift angle of LC loaded CPW-FE phase shifter is slightly different from the desired angle. The other reason is that the separation of the two patch antenna (A and B) is different from designed value because of the fabrication error, and which causes mutual coupling of the two elements.

Figure 9(b) shows the simulated patterns in x-y plane (E-plane). As shown in the figure, that the radiation patterns are almost unchanged under the two phase shift conditions which correspond to the two bias conditions in the experiments. Also, the simulated non-symmetric radiation patterns are thought to be derived from the microstrip lines acting as power feeder line.

5. Conclusion

In this paper, we have proposed and demonstrated the two-element microstrip array antenna incorporating an LC loaded CPW-FE phase shifter. By changing the driving bias voltage applied to the LC loaded CPW-FE phase shifter, up to 90 degrees phase shift could be achieved. As a result, the beam tilt angles of the two-element microstrip array antenna were controlled successfully from 0 to 26 degrees. The tendencies of the measured results are in good agreement with those of numerical simulations. We have also confirmed that the beam scanning time (beam switching time) was the same as the response time of the LC loaded CPW-FE phase shifter, thus LC with faster response time will be very attractive for high-speed operation of these array antennas. We believe that these results will be useful in developing a versatile and electrically controllable microstrip array antenna for future broadcasting satellite applications.

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