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New MUSCAT Array with Parasitic Elements Toward Wide Scanning Range

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1. *Introduction*

Wireless communication systems such as satellite communication systems and Fixed Wireless Access (FWA) systems usually employ directive antennas. In these systems, the direction of the beam must be adjusted. Recently, electronically controlled beam-scanning antennas for high-speed wireless communication systems have been studied [1][2]. For user terminal stations, an antenna that can provide wide beam steering is needed to communicate with satellites or base stations in various directions.

We previously proposed a series-fed beam-scanning array antenna employing MUlti-Stage Configured microstrip Antenna with Tunable reactance devices (MUSCAT) [3]. In this antenna, the microstrip antennas have the tunable reactance devices, and work as phase shifters as well. This configuration can reduce the device loss because less current flows into the devices in this antenna than flows into in the antenna that has separate antennas and phase shifters comprising the tunable reactance devices on feedlines [4]. Furthermore, the MUSCAT array has several unit element groups, which have a multi-stage configuration, and this mechanism multiplies the amount of the phase shift and achieves wider beam scanning than the conventional one [4]. However, all of the unit element groups must have the same dimensions to give the flat phase front to the radiation, and this causes a tapered radiation power distribution in the array because of its series fed configuration. To enhance the beam scanning range, a new idea is needed that can abate the tapered radiation power distribution without distortion of the phase front.

In this paper, we propose using the MUSCAT array employing parasitic elements, which are placed at both ends of the rectangular microstrip antennas. By employing various widths of the parasitic elements we can control the radiation power because the wider the parasitic element becomes the more radiation is generated. The MUSCAT array configuration, whose parasitic element widths gradually become wide toward the end of array without changing the dimensions of the series fed rectangular microstrip antenna, can abate the radiation power distribution with only a slight phase error. That is, wide beam scanning can be easily achieved.

2. *Configuration of Proposed MUSCAT Array with Parasitic Elements*

Figure 1 shows the configuration of the MUSCAT array with the parasitic elements. Each element group is identically constructed with four rectangular parasitic microstrip antennas and three rectangular microstrip antennas, which are placed close to each other and are connected serially by the conductor lines. The lines connecting these antennas are configured at alternate ends of the patch antenna in order to cancel the undesired radiation generated by the lines. Each microstrip antenna has two reactance devices, which can be tuned using DC-voltage. These devices are attached to both ends of the microstrip antenna, and connect the antennas and the ground plane conductor to the backside of the substrate. The MUSCAT array is constructed of a number of unit element groups, which are placed at regular interval D. All of the unit element groups have the same dimensions of the serially connected microstrip antennas and the parasitic microstrip antennas have various widths.

In our configuration, an RF-signal and bias are fed to the unit element group from the same port. The phase of a microstrip antenna can be tuned by changing the DC-voltage because the change in reactance causes a resonant frequency shift in the antenna. A slight resonant frequency shift causes a slight impedance change in the microstrip antenna; however, this mechanism can achieve a large phase shift because several microstrip antennas comprising the unit element group can provide several times

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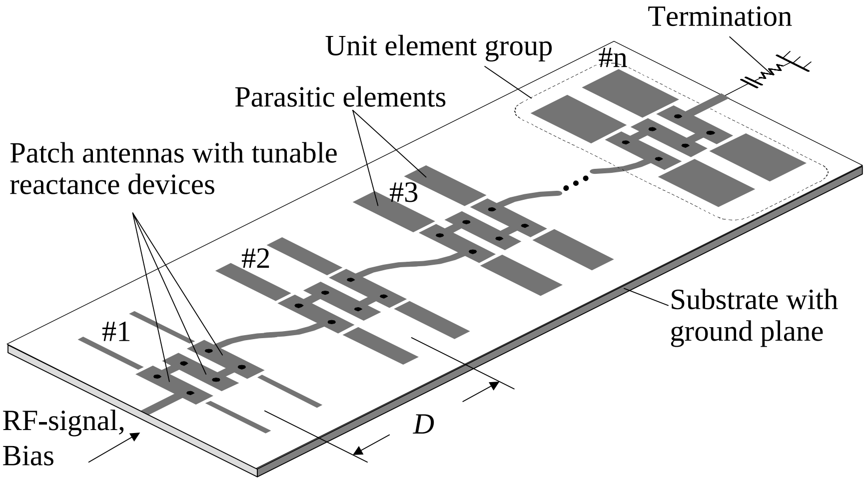

Fig. 1 Configuration of MUSCAT array with parasitic elements.

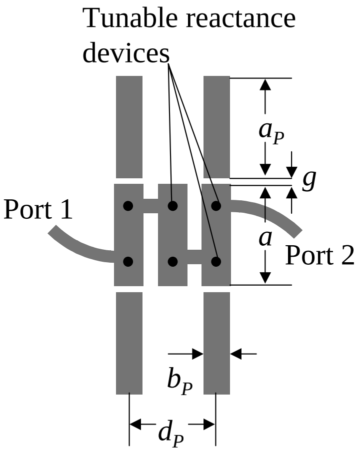

Fig. 2 Unit element group configuration

the phase shift compared to a single microstrip antenna. The phase difference between the neighboring unit element groups can be controlled uniformly because all of the multi-stage configured microstrip antennas except the parasitic elements in the unit element groups have the same dimensions, and this configuration allows us to achieve easy beam steering with only a single DC-voltage control. However, when only the unit element groups, which have the same dimensions, are employed, the tapering of the radiation power distribution occurs in the array. On the other hand, changing the dimensions of the rectangular microstrip antenna can control the radiation power, but this causes the phase front distortion in the radiation. These problems affect the beam scanning performance.

The parasitic elements can be used to control the radiation power of the unit element group. Changing only the width of the parasitic element enables easy control of the radiation power with only slight phase error. The unit element group with wide parasitic elements can generate more intense radiation than that with narrow parasitic elements. By utilizing this characteristic, the MUSCAT array, whose parasitic element widths gradually become wide toward the end of the array without changing the dimensions of the series fed rectangular microstrip antenna, can improve the radiation power distribution and enhance the beam scanning performance. Furthermore, this configuration can be easily fabricated on a single layer dielectric substrate.

To evaluate the phase shift and radiation performance in the unit element group with parasitic elements, we analyzed our configurations using the moment method [5].

3. *Performance of One Unit Element Group*

Figure 2 illustrates the configuration of our new unit element group with parasitic elements. Here, the element spacing of the serially connected microstrip antennas is set to 0.11 λ_0 (λ_0: wavelength in free space); the element spacing, d_P, of the parasitic elements is 0.21 λ_0; the length, a, of the microstrip antenna is 0.28 λ_0; the length, a_P, of the parasitic elements is 0.32 λ_0; and the gap, g, between the parasitic antenna and microstrip antenna with tunable reactance devices is 0.004 λ_0. The relative dielectric constant of the substrate is 2.2, the loss tangent of the substrate is 0.0008, and the thickness of the substrate is 0.02 λ_0. The varactor diode, HVU316 (Renesas Technology, Tokyo, Japan), is employed as a tunable reactance device. We analyze the S-parameter and radiation versus the width of the parasitic elements, b_P, at 2.4 GHz.

The analyzed $|S_{11}|$ and insertion loss versus the phase shift in the unit element group are shown in Fig. 3. Here, the insertion loss is defined as the loss caused by the devices, the conductors, and dielectrics, and does not include the radiation loss. Based on these results, we find that $|S_{11}|$ of our new configuration has a low reflection of less than –15 dB, and is similar to that without parasitic elements. The figure also shows that the insertion losses of the proposed configuration and that without parasitic elements are in good agreement. This means that the parasitic elements affect slightly the impedance and insertion loss of the unit element group. The reason why the proposed configuration slightly improves the loss is that the parasitic elements enhance the radiation power and reduce not only the transmission power to the cascaded microstrip antennas, but also the current in the devices.

Figure 4 indicates the radiation power and phase of the unit element group. Here, the analysis results are obtained by assuming the DC-voltage of 14.5 V, and the phase in this figure represents the relative value of $\angle|S_{21}|$. The figure shows that the unit element group with a wider parasitic element generates a higher radiation power and the unit element group with $b_P = 0.2\ \lambda_0$ approximately triples the radiation power compared to that with $b_P = 0.02\ \lambda_0$. Furthermore, we find that the phase variation caused by changing b_P in this range is less than 10 degrees. These results show that the radiation power can be easily controlled with a slight phase change by changing the width of the parasitic elements.

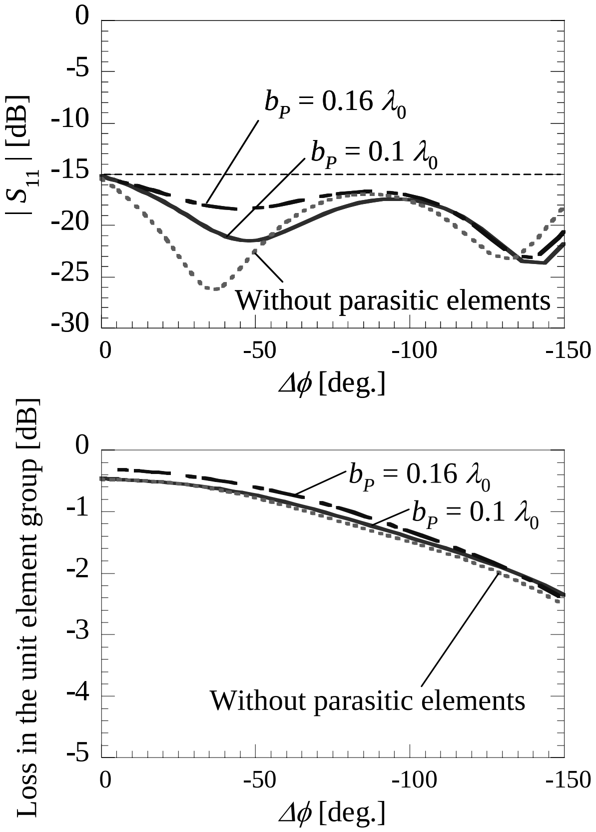

Fig. 3 $| S_{11} |$ and insertion loss of the unit element group versus phase shift.

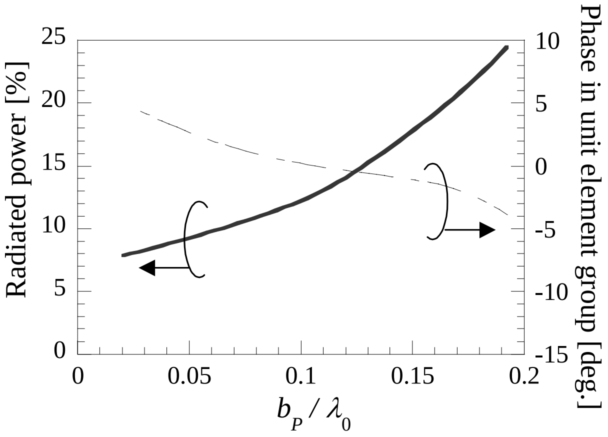

Fig. 4 Radiated power and phase of unit element group versus width of parasitic elements.

4. ***Beam Scanning Property***

To clarify the effectiveness of controlling the radiation power distribution using the parasitic elements, this section presents the analysis results of the radiation performance of the MUSCAT array employing four unit element groups. Here, the spacing, *D*, between the neighboring unit element groups is set to 0.5 λ_0, and all other parameters are the same as those described in the previous section. The dimensions of the parasitic elements are selected to obtain approximately flat radiation power distribution when the DC-voltage is 14.5 V.

Figure 5 shows the radiation power distributions in the designed array. We find that the proposed configuration greatly reduces the radiation power difference compared to the conventional configuration. The radiation pattern of the designed array is indicated in Fig. 6. We find that there is no high sidelobe level or beam splitting of the mainlobe. These results show that the reflection caused by the miss-match of the impedance in the unit element group is sufficiently low in the case of this scanning range. Figure 7 indicates the relative gain versus the beam-scanning angle. We find that the beam scanning range within 3-dB gain attenuation is approximately 35.5 degrees for the proposed antenna, and 28.3 degrees in the conventional configuration. In other words, the proposed antenna improves the beam-scanning angle by 25%.

5. *Conclusion*

This paper proposed a MUSCAT array with parasitic elements to enhance the beam scanning range by suppressing the tapering of the power distribution. We showed that by employing various widths of the parasitic elements, the radiation power can be tripled within a 10-degree phase error in the unit element group. The analysis results of the beam scanning performance in the four unit element group MUSCAT array indicated that the proposed configuration enhances the beam scanning range by 25%. From these results, we show that this configuration with the parasitic elements is effective in achieving a wide beam scanning of the MUSCAT array.

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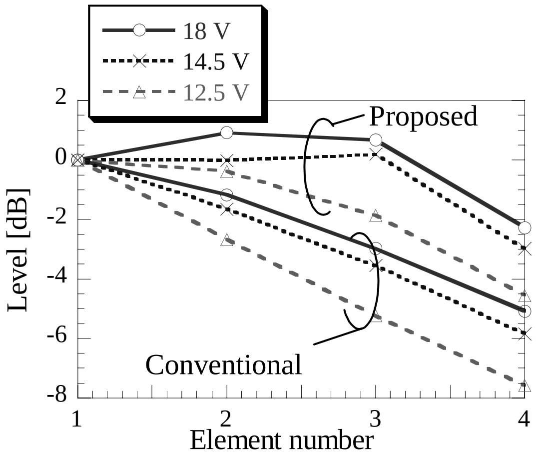

Fig. 5 Radiation power distribution in MUSCAT array

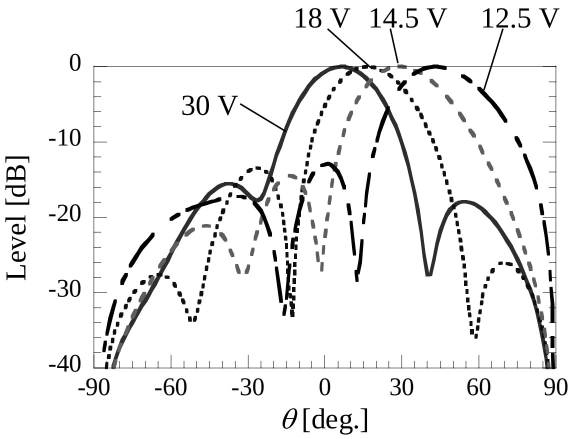

Fig. 6 Analyzed radiation patterns

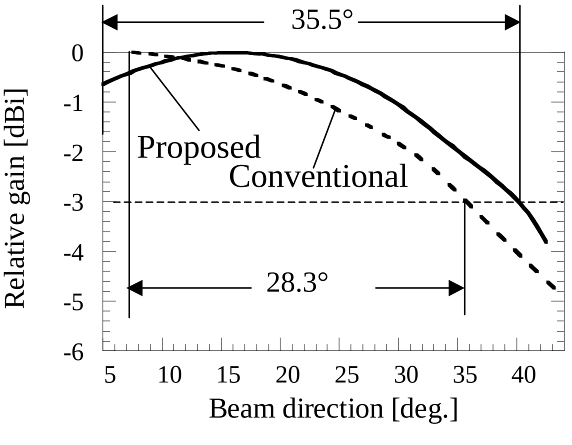

Fig. 7 Relative gain versus beam direction