Practical Active Phased Array Antenna in the Assembly of Sub-arrays with Partial Drive Technique

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1. Introduction

A conventional active phased array antenna (APAA) for a military purpose is composed of modules each of which includes a radiator, a high power amplifier (HPA), a low noise amplifier (LNA), a phase shifter and combiners on a printed circuit board (PCB). Therefore, such a APAA is thicker than the longitudinal size of the PCB. Several attempts of planar APAAs were proposed to overcome the disadvantages [1][2]. A thinning technique or a sparse array were to reduce the element number [3]. Another attempt is to use the identical elements and electronics in realizing a desired field distribution on an array aperture [4].

Our project aims to drastically reduce the cost and improve handling capability of an APAA for practical applications [5] [6] [7]). The key technologies are as follows:
(1) Partial drive technique of radiators [8].
(2) Switch of Micro Electro- Mechanical System at radio frequency (RF-MEMS).
(3) Amplifiers of Monolithic Microwave Integrated Circuit (MMIC).
(4) Integration of an antenna in flat layers.

By partial drive technique, the number of driven elements can be lessened to a half of the whole, as is quite effective to feeding simplification and eventually cost reduction. Also in integrating a large array antenna, it is effective to divide the antenna into sub-arrays of the same configuration from the viewpoint of manufacturing, test and inspection.

On the other hand, the grating lobes in the partial drive case would be larger than those in the full drive case. In order to prevent the grating lobe growth, a randomizing technique was proposed [9]. But a randomized array antenna tends to be difficult to divide into sub-arrays with identical shape and configuration.

This paper presents a new design concept of sub-arrays which can prevent the increase of grating lobes due to partial drive technique. The availability is confirmed by theoretical analysis and simulation.

2. Radiation Characteristics of an Assembled APAA

2.1 Periodicity of Array Distribution

In a partially driven array antenna, the driven elements and parasitic elements are arranged to have strong coupling each other. Though the parasites act as radiating elements, those two kinds of elements have slightly different characteristics. Accordingly there tends to exist periodicities longer than an element separation, which cause large grating lobes. Therefore, design principle for arraying to lower the grating lobes is essential, especially to APAA in the current R&D project.

For explanation purpose, we adopt a two line array antenna as shown in Fig. 1. The radiation pattern of the array on the first line (j = 1) is expressed by Eq. (1).
where \( k \) : wave number, \( a \) : the separation between elements, \( \alpha \) : angle in the z-x plane, \( \phi_i \) : driving phase of the i-th element. The amplitude \( a_i \) is unity for a driven element and smaller than unity for a parasitic element, respectively. When all elements are driven in phase, the wave is radiated perpendicularly to the x-axis regardless of the number ratio of two kinds of elements.

Next we consider the second line \((j = 2)\) with the separation \( b \). To scan the beam in the y-z plane, the phase is changed between the first line. The amplitude of the radiated waves is dependent on the number ratio of two kinds of elements. If the ratio is constant, 4:3 in this case, two lines are esteemed equivalently to be two identical radiators, or the periodicity in this case is equal to the separation of elements. Otherwise, the ratio of the third line may fluctuate, and the periodicity is greater than the element separation \( b \).

According to the above discussion, the number ratio of driven and parasitic elements should be constant between lines. An example is shown in Fig. 2 in the case of 192 elements which are arranged on three base lines of a regular triangle. In the case of Fig. 2 (a), the numbers of two kinds of elements are almost equal along the reference line, the y-axis in this case, as shown in Fig. 3 (a). On the other hand, if driven and parasitic elements are arranged alternately as shown in Fig. 2 (b), the numbers periodically change as shown in Fig. 3 (b).

As easily presumed, there are plural reference lines where the ratio should be almost constant. In Fig. 2 of a triangular arrangement, three reference lines exist.

### 2.2 Simulation Result

The radiation patterns were studied by simulation using the MOM software of FEKO. The assumed frequency is 12.5GHz. The separation between elements is 0.5 \( \lambda \) in three directions of a regular triangle. The element is 0.5 \( \lambda \) long, and set at 0.5 \( \lambda \) height from the reflector plane.

The results for two allocation cases of parasitic elements are shown in Fig. 4. In the desirable case with unity ratio along the reference line, the grating lobes are almost the same as the fully driven case. In the undesirable case, however, the grating lobes grow high at El = 10 deg., as is close to 17 deg. derived from the array theory.

Beam scanning characteristics in El plane in the desirable case is shown in Fig. 5. The gain degradation and grating lobes growth are negligible between Az angles.

### 3. Division of an Array Antenna into Sub-arrays

In order to manufacture a large array antenna, say, with 192 elements, the antenna should be divided into identical sub-arrays. The way of division has much freedom. In Fig. 2, the antenna is devided into 12 sub-arrays, each of which is composed of 16 elements. The sub-arrays are arranged with 60 degree rotation. The resultant array distribution successfully keep the criteria of the former discussion.

The manufactured model antenna is shown in Fig. 5 with a sub-array removed in order to indicate the layer structure of the array antenna.

### 4. Conclusions
Division of an array antenna into sub-arrays was formulated. The criterion for desirable allocation of elements is that the number ratio of the driven and parasitic elements should be constant.

The simulation result shows that grating lobes are significantly suppressed by this design, which are otherwise caused by larger periodicities than the element separation. Accordingly, the theoretical consideration has been confirmed.

An APAA of any size may be constructed in the assembly of sub-arrays of identical configuration. This is a great advantage in manufacturing, test and inspection.

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References


Figure 1: An element array on two lines.
(a) A desirable case.

(b) An undesirable case.

Figure 2: Examples of sub-array division.
- ● driven,
- ○ parasitic

Figure 3: The number of driven elements along the y-axis.

Figure 4: Radiation patterns aiming at El = 60 deg. in desirable (---) and undesirable (-----) cases.

Figure 5: Elevation patterns of the beams pointing at El= -45deg in several planes of Az=0 to 330deg.

Figure 6: Outlook of a manufactured APAA with one sub-array removed.