A Method of Moments Analysis and Design of RLSA by Using Only a Dominant Mode Basic Function and Correction Length for Slots

#Nguyen Xuan Tung[1], Jiro Hirokawa[1], Makoto Ando[1], Osamu Amano[2],
Takaomi Matsuzaki[2], Shuichi Koreeda[2], Kesato Takahashi[2]
[1] Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Japan
tungnguyen@antenna.ee.titech.ac.jp
[2] NEC Toshiba Space System, Tokyo, Japan

Abstract- **In this paper, a well-know Method of Moments (MoM) is introduced together with the definition of a constant slots correction length in order to simulate the behaviors of slots on a rectangular waveguide having narrow wall. Large array radial line slotted antenna (RLSA) is analyzed and designed using this method, and their measured performances suggest the accuracy of the MoM and the importance of the slot correction length.**

I. INTRODUCTION

Recently, as the growing development of computer science and technology, high accurate simulators have been utilized to predict the behaviors of Electromagnetic Field (EMF) based on EM Theory and Analytical Methods. However, when the EM devices are electrically large i.e. 30000 radiating elements [1], those simulators still require a big amount of computational time as well as a large virtue memory and a super high-speed processor. To this end, conventional and well-know MoM turns out to be advantageous.

For slotted array antennas, estimation of coupling characteristics of the slots is very important for an accurate and fast design. Basically, slot coupling can be controlled by geometrical parameters of the slots (length, width and shape). Dependence of slots coupling upon their lengths was thoroughly studied and presented by Hirokawa [2]. On the other hand, an equivalent slot length was introduced to compensate the modeling errors considering the practical slots have round-ended shape [3].

This paper is ordered as follow: the estimation of a newly defined slot correction length to enhance the accuracy in slot coupling analysis of slots is reported at first, and follows by the fast analysis/ design procedure of a large array RLSA in Ka band based on the MoM with consideration of the slot correction length. Finally, measured performances of the fabricated antennas validate the use of the slot correction length as well as the analysis/ design procedure.

II. SLOT CORRECTION LENGTH

In MoM analysis, slot is substituted by a magnetic current M$_k$ (k = 1, 2), and this current distribution is longitudinally expanded by a number of so call basis functions, which are normally in sinusoidal form as in (1), (2).

$$\mathbf{M}_k = \sum_{i=1}^{N_b} A_{ki}\mathbf{m}_i \qquad (1)$$

$$\mathbf{m}_i = \hat{\xi}\sin\{\frac{i\pi}{l}(\xi + \frac{l}{2})\} \qquad (2)$$

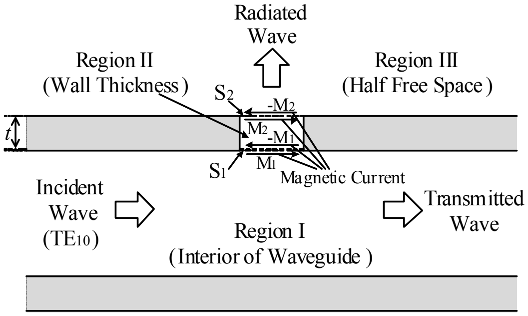


Figure 1: Canonical regions and equivalent slot in MoM

Fig. 1 shows the MoM modeling of a slot cut on a rectangular waveguide. The number of basic functions N_b determines the accuracy of the MoM analysis, the more number is the better accuracy can be achieved. However, in order to reduce the calculation time, only a dominant mode basic function is utilized together with a slot correction length, and this combination can produce the slot coupling just as precise as the use of multi-mode basic functions. This matter is well reported by Ando et al., [4].

Fig. 2 shows the unit slot pair model for design of RLSA. In this particular case, this model consists of a double layer waveguide structure and two orthogonal slots on top. The periodic boundary walls are applied to take into account the mutual coupling between adjacent slots in circumferential direction-ϕ. Fig. 3 presents the coupling factor analysis; the black, red, and dotted lines indicate the results obtained by MoM with 1-mode basic function (N_b = 1) i.e., 1-mode MoM, MoM with multi-mode basic functions (N_b = 15) i.e., multi-mode MoM, and High Frequency Structure Simulator – HFSS, respectively. While the multi-mode MoM and the HFSS lines are in reasonable agreement, it is observed that the 1-mode MoM line differs from those two. Furthermore, in order to produce the same coupling, slots analyzed by 1-mode MoM-

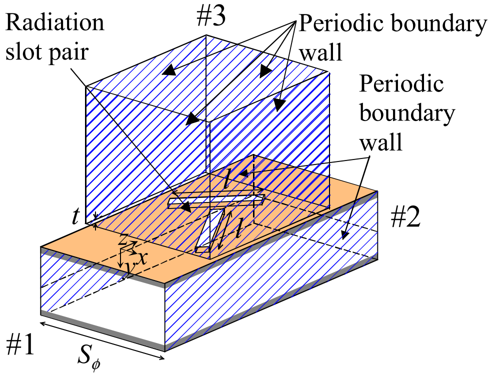


Figure 2: Unit pair model for MoM analysis

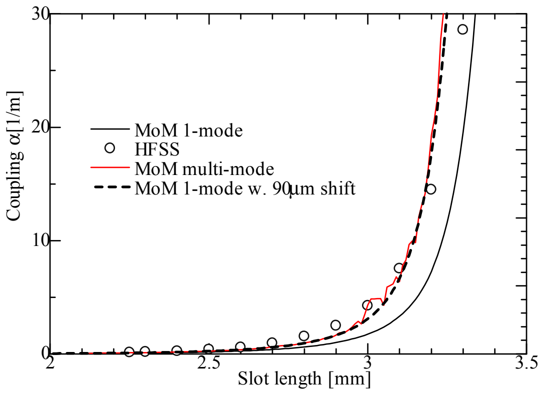


Figure 3: Slot coupling analysis

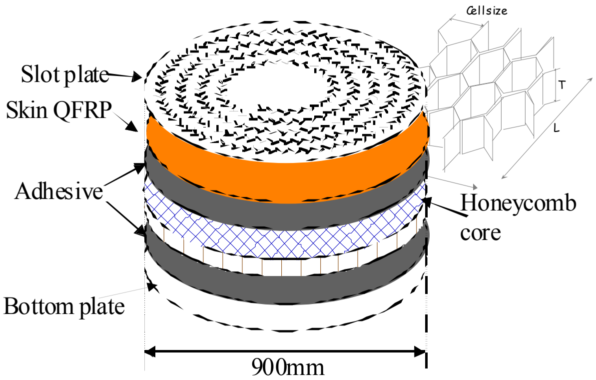
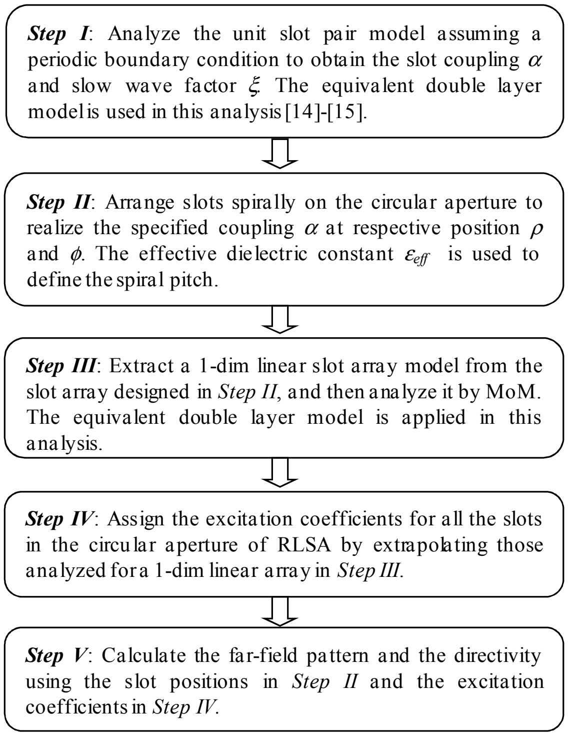


Figure 4: Structure of Multilayer RLSA with honeycomb



Step I: Analyze the unit slot pair model assuming a periodic boundary condition to obtain the slot coupling α and slow wave factor ξ. The equivalent double layer model is used in this analysis [14]-[15].

Step II: Arrange slots spirally on the circular aperture to realize the specified coupling α at respective position ρ and ϕ. The effective dielectric constant ε_{eff} is used to define the spiral pitch.

Step III: Extract a 1-dim linear slot array model from the slot array designed in *Step II*, and then analyze it by MoM. The equivalent double layer model is applied in this analysis.

Step IV: Assign the excitation coefficients for all the slots in the circular aperture of RLSA by extrapolating those analyzed for a 1-dim linear array in *Step III*.

Step V: Calculate the far-field pattern and the directivity using the slot positions in *Step II* and the excitation coefficients in *Step IV*.

Figure 5: Fast Design/ Analysis procedure for large array RLSA

are always longer than that of those analyzed by multi-mode MoM or HFSS. Put differently, couplings produced by 1-mode MoM would be just the same as ones obtained from multi-mode MoM if we just shortened the slots a constant length of Δl. From fig. 3, we can derive a $\Delta l = 90\mu m$ for the slot correction length. The constant shift of $-90\mu m$ (dashed line) from the 1-mode MoM is almost identical with one produced by multi-mode MoM, which reassures our prediction.

III. FAST DESIGN/ ANALYSIS OF A HIGH GAIN RLSA

A. Antenna Structure

A high gain, light weight planar slotted array antenna is required for space application [1]. To enhance the mechanical strength and reduce the antenna's weight, a honeycomb-type structure was utilized. Together with some additional adhesive and Quartz Fibre Reinforced Plastic (QFRP) – made skin layers, it creates a multilayer structure of the oversized radial waveguide. The antenna is fed by a simple coaxial line which produces a cylindrical wave travelling inside the multilayered waveguide. On the top metal plate, thousands of slots are etched to radiate the EM field. Fig. 4 details the antenna's structure and it is also well reported in [1].

B. Fast Analysis/ Design procedure and Role of the slot correction length

Since this RLSA is for practical use in outer space and the fabrication cost is expensive, it is important that the antenna's performance must be well-predicted before going to the fabrication phase. However, its electrically large and complicated structure requires not only the appropriate analytical method but also a simplified model of the waveguide structure. For the first issue, a MoM is applied to simulate the slot couplings and design the antenna. For the second issue, an equivalent double layer model of the waveguide structure is introduced to reduce the complexity in calculation [1]. Fig. 5 represents a fast analysis/ design procedure based on the MoM and the equivalent double layer model.

It is noted that in the 1st and 3rd steps, the MoM is used, and so should be the slot correction length in order to obtain high accuracy of slot couplings. The correct use of the slot correction length $\Delta l = 90\mu m$ can be stated as follow:

- Slot couplings are calculated by 1-mode MoM without considering the slot correction length. At this state, we have typical slot with a length of l_{ana}, for example.
- Slots obtained from previous analysis are shortened by a constant Δl=90μm, and sent to the maker for the fabrication. The fabricated length is $l_{fab} = l_{ana} - \Delta l$.
- Extracted slots with typical length of $l_{fab} = l_{ana} - \Delta l$ are used for the 1-dimensional linear array analysis. To obtain high accuracy, slot with a length of l_{fab} should be analyzed by multimode MoM. However, 1-mode MoM can also be utilized by just simply adding Δl to l_{fab}. In other words, at this state, by applying 1-mode MoM to analyze slot with length of $l_{ana} = l_{fab} + \Delta l$, accurate results are still produced.

Fig. 6 explains how the slot correction length was applied in this paper and the correct use of it is left for the future. It suggests that in design/ analysis procedure, the slot correction length can be neglected and the 1-mode MoM still produce accurate results for predicted antenna performance. However, the slot correction length must be taken into account in the fabrication phase. Notations 1, 2 and 3 are used to differentiate the antenna performance results, which will be discussed latter.

IV. MEASURED ANTENNA CHARACTERISTICS

A 900mm RLSA was designed and fabricated. The design frequency is 32GHz and expected gain is more than 44.1dBi. - For the fabrication, the equivalent slot length [3] was introduced but the slot correction length [4] was not taken into account.

Fig. 7 compares the measured and predicted reflection coefficients. These two are in a good agreement. At the design frequency of 32GHz, measured reflection coefficient is about -17dB while it is less than -15dB in the 31.2~32.3GHz frequency band.

Antenna directivity and gain are presented in Fig. 8. Black and red lines account for the directivity and gain, respectively. Directivity and gain are predicted without considering any correction length and are plotted by the dashed lines (noted as no. 1). Peak frequency is 32.1GHz for both directivity and gain. The measured performance is 200MHz shifted to lower frequency since the slot correction length was neglected in fabrication process, as indicated by the solid lines (noted as no. 2). The prediction with consideration of the slot correction length (dashed-dotted lines, noted as no. 3) is in a good agreement with the measurement, which reassures the necessary of slot correction length in the fabrication. As for antenna specification, a gain of 44.6dBi at 32GHz already satisfies the system requirement, even though a considerable loss of 3-4dB still exists due to the lossy honeycomb material [5].

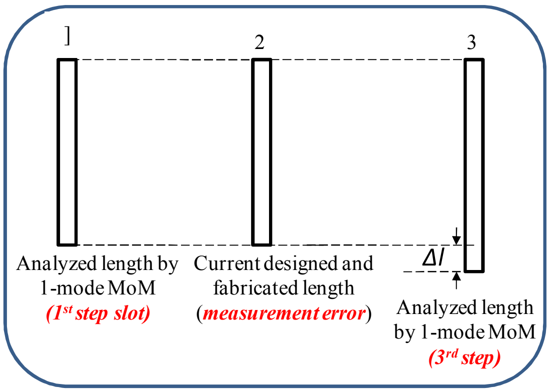

Current design/ analysis and fabrication (this paper)

Figure 6: Role of the slot correction length in design/ analysis procedure and fabrication phase

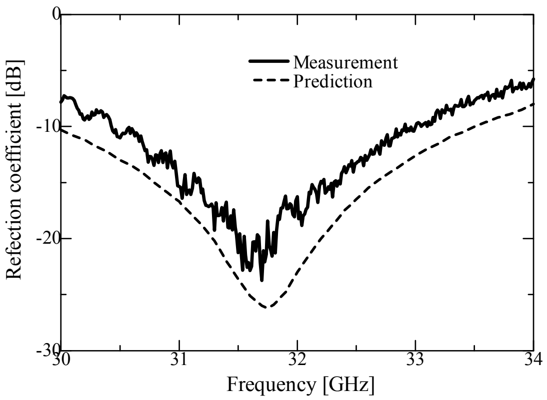


Figure 7: Measured reflection coefficients

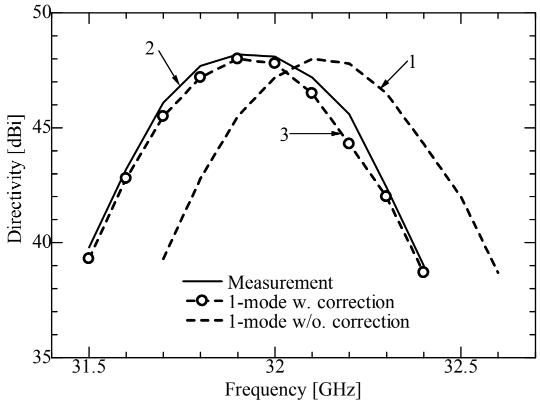


Figure 8: Measured and predicted performance

V. CONCLUSION

A fast analysis/ design procedure of a large array RLSA was developed based on the MoM and a simplified, equivalent double layer waveguide structure. A constant slot correction length was introduced to enhance the accuracy in MoM analysis using only a dominant mode of the basic function. The measured antenna performance is in a good agreement with the predicted one, which explains our procedure and assures the importance of the use of the correction length. In practical point of view, a RLSA which can produce a very high gain of more than 44dBi and a super light weight of about 1kg is advantageous for space applications.

ACKNOWLEDGMENT

This work was conducted in part as "the Research and Development for Expansion of Radio Wave Resources" under a contract with the Ministry of Internal Affairs and Communications. It was also supported by the JAPAN Aerospace Exploration Agency (JAXA). The authors thank Mr. Harada at NEC Toshiba-Space Systems for his support with the experiments.

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