Wave Analysis Method of Probe-Fed Radial Line Planar Antennas for Uniform Aperture Field Distribution

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1. Introduction

We propose a wave analysis method of a probe-fed Radial Line Planar Antennas (RLPA's) for uniform aperture field distribution. The probe-fed RLPA's [1]-[4] have an advantage of high efficiency, because the excitation probes of the radiating elements can be fed by a standing wave in the radial line with a short-circuited termination of its end. The authors proposed an analysis method [4] of aperture field distribution by calculating mutual coupling of probes using the Electromotive Force (EMF) method. Recently, other analysis methods of RLPA's were reported [5][6], that use probes as a feeding structure of the radiating elements. However, the method [5] is not realistic because all probes inside radial line were imitated monopole antennas and their diameters are not considered. The analysis model [6] inevitably assumes rotational symmetry to the system. Therefore, its application to the scattering that breaks the symmetry is impossible. Also, even the application advisability to the 4 point fed RLPA's is not obvious. In this paper, we describe a wave analysis method of uniform aperture field distribution for a probe-fed RLPA. This method can accommodate the effect of all the conductors including the termination wall by introducing the concept of equivalent posts [7]. It is possible to apply it to the cavity of various geometries including the circular one. Good correspondence has been confirmed between measured and calculated values on the aperture field distribution.

2. Theory

Figure 1 shows a structure of probe-fed RLPA. The radiating elements are arranged in the concentric circles around the center feed, and are excited by utilizing the mutual coupling of probes in a radial line.

An analysis is carried out for the aperture field distribution by using the self and mutual impedances of the probes and shorted posts in the radial line, respectively. The termination wall is imitated by the shorted posts. The impedance matrix of the probes and posts is expressed as follows:

$$[Z]=\begin{bmatrix} Z_{r_1r_1}+Z_{R_1} & \cdots & Z_{r_1r_n} & Z_{r_1f_1} & \cdots & Z_{r_1f_N} & Z_{r_1p_1} & \cdots & Z_{r_1p_M} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ Z_{r_nr_1} & \cdots & Z_{r_nr_n}+Z_{R_n} & Z_{r_nf_1} & \cdots & Z_{r_nf_N} & Z_{r_np_1} & \cdots & Z_{r_np_M} \\ Z_{f_1r_1} & \cdots & Z_{f_1r_N} & Z_{f_1f_1}+Z_{F_1} & \cdots & Z_{f_1f_N} & Z_{f_1p_1} & \cdots & Z_{f_1p_M} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ Z_{f_Nr_1} & \cdots & Z_{f_Nr_n} & Z_{f_Nf_1} & \cdots & Z_{f_Nf_N}+Z_{F_N} & Z_{f_Np_1} & \cdots & Z_{f_Np_M} \\ Z_{p_1r_1} & \cdots & Z_{p_1r_n} & Z_{p_1f_1} & \cdots & Z_{p_1f_N} & Z_{p_1p_1} & \cdots & Z_{p_1p_M} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ Z_{p_Mr_1} & \cdots & Z_{p_Mr_n} & Z_{p_Mf_1} & \cdots & Z_{p_Mf_N} & Z_{p_Mp_1} & \cdots & Z_{p_Mp_M} \end{bmatrix} \qquad (1)$$

where $Z_{r_nr_n}$, $Z_{f_Nf_N}$, and $Z_{p_Mp_M}$ are the self-impedances of a feeding probe, an excitation probe, and a shorted post, respectively, and $Z_{r_nf_N}$, $Z_{r_np_M}$, and $Z_{f_Np_M}$ are the mutual impedances between the feeding and

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excitation probes, the feeding probe and shorted post, and excitation probe and shorted post, respectively. Z_{R_n} and Z_{F_N} are the characteristic impedances of the feeding and excitation probes. In this analysis, we assume that the self-impedances of the radiating elements are all identical to Z_{F_N}.

The current distribution on the surface of excitation probes and the aperture field distribution are expressed by using (1) as follows:

$$\begin{bmatrix} I_{r_1} \\ \vdots \\ I_{r_n} \\ I_{f_1} \\ \vdots \\ I_{f_N} \\ I_{p_1} \\ \vdots \\ I_{p_N} \end{bmatrix} = [Z]^{-1} \begin{bmatrix} V_{r_1} \\ \vdots \\ V_{r_n} \\ V_{f_1} \\ \vdots \\ V_{f_N} \\ V_{p_1} \\ \vdots \\ V_{p_N} \end{bmatrix} \qquad (2) \qquad\qquad \begin{bmatrix} P_{f_1} \\ \vdots \\ P_{f_N} \end{bmatrix} = \begin{bmatrix} Z_{F_1} & \cdots & Z_{F_N} \end{bmatrix} \begin{bmatrix} I_{f_1} \left| I_{f_1} \right| \\ \vdots \\ I_{f_N} \left| I_{f_N} \right| \end{bmatrix} \qquad (3)$$

For example in the case of the 1 point fed RLPA with port r_1, $V_{r_1} = 1$, $Z_{R_1} = 0$, and the other voltages are zero.

3. Simulation and Experiment

We fabricated a probe-fed radial line power divider. It has total 90 elements arranged on 5 concentric circles. The parameters of the power divider with the operating wavelength λ are $a_f = 0.02\lambda$, $l_f = 0.18\lambda$, and $h = 0.27\lambda$. The radii of excitation probes are all identical to 0.02λ, and the radii of the concentric arrangement circles are 0.50λ, 0.95λ, 1.41λ, 1.97λ, and 2.45λ, respectively, in the radial direction. The insertion lengths of the probes on the respective circles are 0.13λ, 0.17λ, 0.19λ, 0.15λ, and 0.16λ. The aperture field distribution is measured value of the transmission characteristic from the feeding probe to an excitation probe on the respective concentric arrangement circles. The comparison between the calculated and measured value of the aperture field distribution is shown in Table 1. Good arrangement supports the theory.

The aperture field distribution is calculated in the case that the insertion length of probes for each concentric arrangement circles is varied. The parameters of the model are $a_f = 0.02\lambda$, $l_f = 0.18\lambda$, and $h = 0.39\lambda$. The radii of excitation probes are all identical to 0.02λ. Fig.2 shows aperture field distribution. From the result, the aperture field distribution of the adjusted probes is only changed significantly and the others are almost unchanged.

The aperture field distribution is calculated in the case that the radii of each concentric arrangement circle are varied. The insertion lengths of the probes on the respective circles are 0.11λ, 0.13 λ, 0.15λ, 0.15 λ, and 0.16λ. Fig.3 shows aperture field distribution. From the result, the amplitude values for the variable concentric arrangement circle are almost unchanged and only phase values are changed. The aperture field distributions of the other circles are almost not changed.

Using these results, we can design the uniform aperture field distribution. First of all, (I) we choose the radii of the concentric arrangement circles in a half-wavelength step in the radial direction. (II) The uniform amplitude value of aperture field distribution is obtained by adjusting the insertion length of excitation probes. Next, (III) the uniform phase value is obtained by adjusting the radii of the concentric arrangement circles. Fig.4 is shown the calculated results of aperture field distribution. The radiation patterns are shown in Fig.5.

4. Summary

We have proposed the wave analysis method of a probe-fed RLPA. Good correspondence has been confirmed between measured and calculated values on the aperture field distribution. By observing parameter dependence of the feeding network, a method has been proposed to achieve the uniform aperture field distribution. The method is efficient for general geometries of probe-fed RLPA's.

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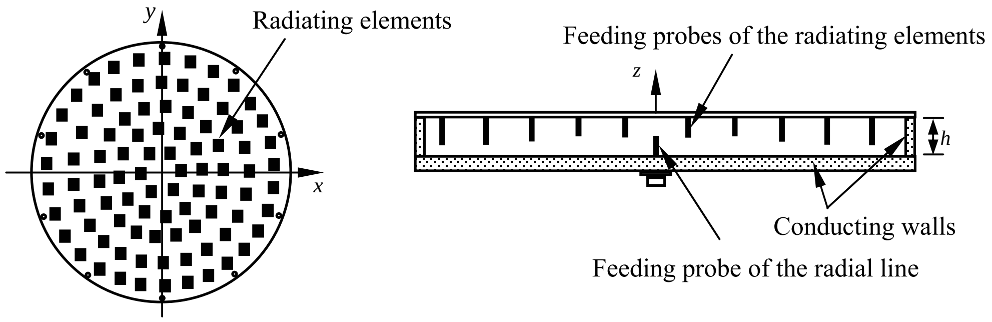
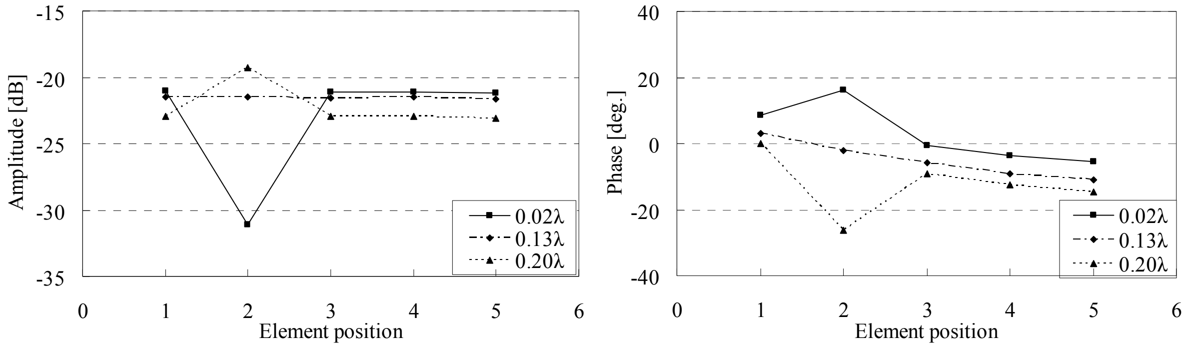


Figure 1: A radial line planar antenna.

Table 1
Comparison of Aperture Field Distribution between Calculated and Measured Values

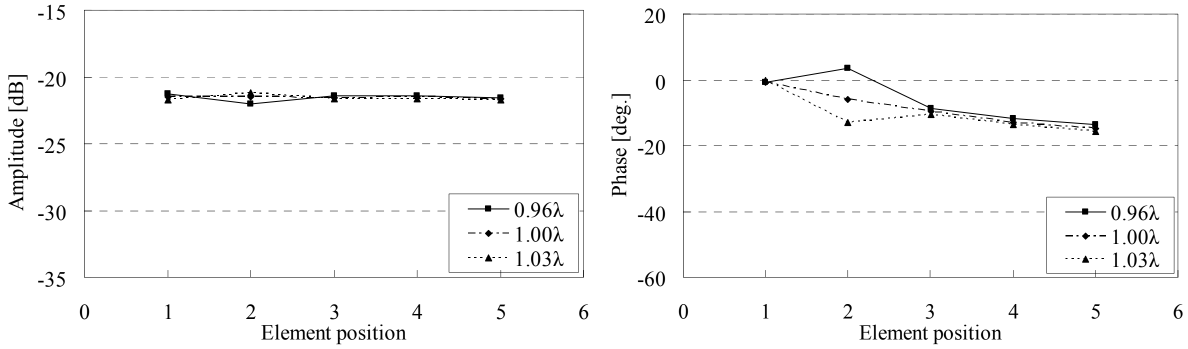
Element circle number	Amplitude [dB]		Phase [deg.]	
	Cal.	Meas.	Cal.	Meas.
1	-19.9	-19.2	-14	-15
2	-20.4	-19.4	168	161
3	-21.4	-20.6	-11	-19
4	-22.7	-23.5	172	163
5	-23.0	-23.5	-10	-21



(a) Amplitude

(b) Phase

Figure 2: Calculated aperture field distribution. (In the case that the insertion lengths of probes for 2nd concentric arrangement circle are adjusted)



(a) Amplitude

(b) Phase

Figure 3: Calculated aperture field distribution. (In the case that the radius of 2nd concentric arrangement circle are adjusted)

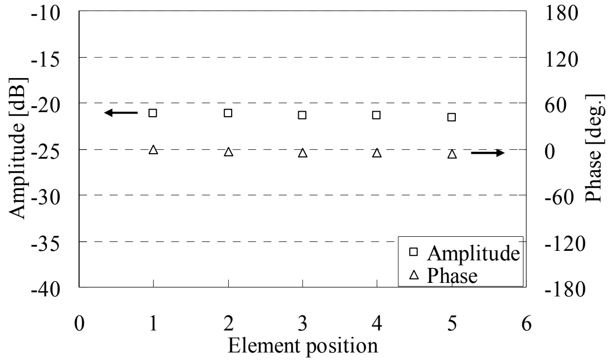


Figure 4: Calculated aperture field distribution.

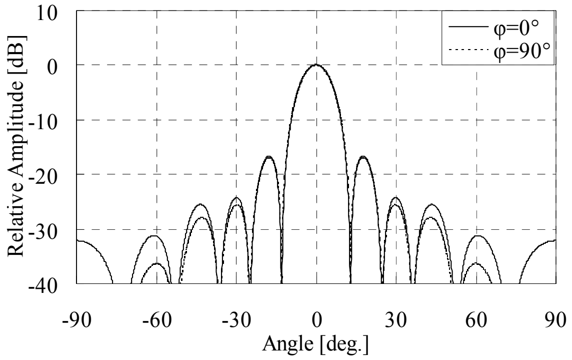


Figure 5: Calculated radiation patterns.