Dual Beam Steering LC-based Holographic Antenna with Coupling Considered Modulation Scheme utilizing Particle Swarm Optimization

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Abstract— **A holographic antenna capable of dual-beam-steering is proposed. Coupling between adjacent cells in the holographic antenna is presented with a simple mathematical model. Utilizing this model, current flow on patches of each cell can be calculated for any given state sequence by simple matrix operations without full wave simulation. This capability is combined with particle warm optimization technique to find the optimal state sequence which radiates similar power for both directions in dual-beam-steering. The optimal state sequences are tested in full wave simulation and it is confirmed that gain difference between both directions was improved to less than 1dB. This antenna and methodology present the possibility of creating any desired beam patterns for various applications, not only for dual-beam-steering by elaborating the mathematical model and activating various states in each cell.**

I. Introduction

A reconfigurable holographic antenna is a substitute of phased array and the beam pattern can be varied by controlling each cell containing a variable material. In general, modulating equation which enables generating main lobe in desired direction is well-known. However, since this equation has the assumption that there is no coupling between adjacent cells, the state sequence derived by the equation shows worse performance in full wave simulation than expected [1].

Therefore, a simple mathematical model of current flow in each cell considering the coupling effect was presented in this paper. Through this model, it was possible to infer the current flow in each cell for any given state sequence and accordingly it was possible to infer beam pattern for the given state without full wave simulation which takes long time. An appropriate cost function was constructed with the radiation pattern inferred by the mathematical model and particle swarm optimization technique was used to find an optical state sequence that allows similar radiation in any two directions within -40° to 40° at 10 GHz. The resultant beam pattern was compared with the previous one generated from the state sequence which was derived by the original modulating equation.

II. Antenna structure, and design methodology

The structure of the designed holographic antenna is shown in Fig. 1. Each cell has a slot etched on the top surface of the SIW, and a liquid crystal (LC) which is an anisotropic material, is placed on the slot. There is a patch on it, which controls the LC and operates as a radiating structure combined with the slot. The arrangement of LC is changed by applying appropriate voltage to the patch and since it is an anisotropic material, the resonance frequency of the single cell also changes. The single cell radiates moderate power for the case when the bias is on and little power for the other case at 10GHz. As a result, the effective polarizability of the single cell changes, and the value of each state can be mapped as 1 and 0, respectively.

The antenna is composed of 43 cells. As TE_{10} mode of the SIW passes through the 43 cells, each cell radiates with its

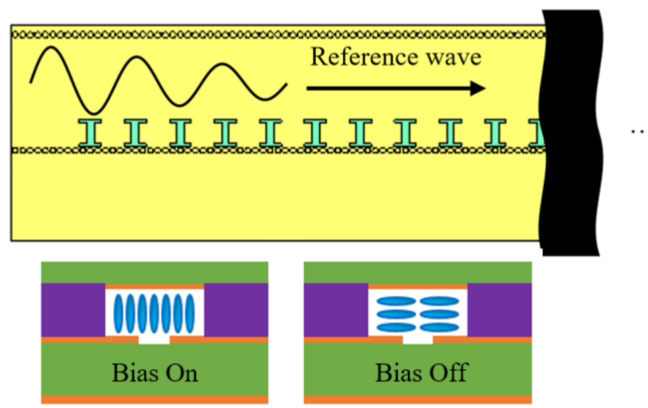

Fig. 1. Overall structure of the holographic antenna and LC alignment in single cell for each bias state.

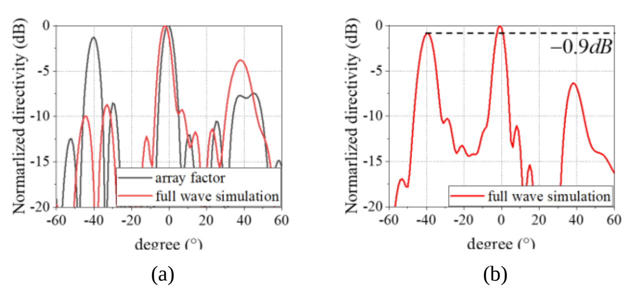

Fig. 2. Beam patterns of the sequence state steering to -40° and 0° directions. (a) original modulating equation (b) particle swarm optimization.

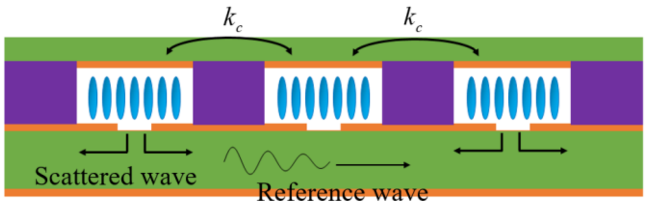

Fig. 3. Relation of the current on patch including the coupling effect.

effective polarizability and finally produce a beam pattern. The binary equation which can be used to obtain a state sequence capable of generating a main lobe in a specific direction is well known [2]. The equation can be easily modified so that it gives the state sequence which enables dual-beam-steering. The state sequence required for dual beam in –40°, and 0° directions was obtained by the modified equation for example. It is applied in full wave simulation and the resultant beam pattern was compared with the calculated array factor as shown in Fig. 2(a). It can be confirmed that the dual beam is not properly formulated in the desired direction unlike the calculated array factor. The cause of this problem is that the modulating equation is derived under the assumption that there is no coupling between adjacent cells. However, in the case of the actual holographic antenna, the coupling is likely to be strong because cells are placed close. Therefore, the desired beam pattern may not be obtained by the state sequence from the equation because each cell cannot radiate with the designed magnitude and phase due to the coupling issue [1].

To solve this problem, relation of current flow on patches in each cell including the coupling effect is presented as shown in Fig. 3. I_n represents the current flow on the patch in nth cell. I_n is dominantly fed from the reference TE_{10} mode and also affected by the current in adjacent cells. The coupling constant k_c represents how much I_n is affected by adjacent cells. In addition, there is additional TE_{10} mode inside the SIW which is generated by scattering effect of the current flow in all the cells. Therefore, the scattered TE_{10} mode should also be taken into account and this wave has the same effect on I_n as the reference wave. The total relation of I_n can be expressed by n equations. These equations can be modified into the form of a simple matrix as follows.

$$\begin{pmatrix} -1 & k_c + sc_{12} & \cdots & sc_{1N} \\ k_c + sc_{21} & & \ddots & \vdots \\ \vdots & & & \\ sc_{N1} & & \cdots & -1 \end{pmatrix} \begin{pmatrix} I_1 \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} -R_1 \\ \vdots \\ -R_N \end{pmatrix} \tag{1}$$

N, R_n and sc_{nm} are the number of cells, current in nth cell induced by the reference wave, and the current inducing coefficient in nth cell by the scattered wave produced by mth cell, respectively. All these coefficients constituting the matrix can be extracted from single cell and dual cell simulation. By multiplying the inverse of the matrix on both sides, it is possible to infer the amount of current flow in each cell which includes variation caused by the coupling effect for any given state sequence. Accordingly, it is possible to predict beam pattern generated from the state sequence without full wave simulation which takes long time.

Particle swarm optimization was used to configure the desired dual beam pattern. Cost function is as follows.

$$f(SS) = -G_1 - G_2 + abs(G_1 - G_2) + 10 \cdot SLL \tag{2}$$

G_1, G_2, SLL are the gain at both directions and sidelobe level of the beam pattern for the given SS, respectively. All other parameters in the particle swarm optimization is set to default value produced by MATLAB. The state sequence found through the optimization was applied to full wave simulation to confirm the beam pattern and the resultant beam pattern is shown in Fig. 2(b). It is confirmed that the dual beam is properly generated, and the gain difference is within 1dB which is the enhanced value compared to the result of the original modulating equation.

III. Conclusion

An LC-based holographic antenna capable of generating dual beam toward any two directions within -40° to 40° at 10 GHz is proposed. The original modulating equation has the limitation that it does not consider the coupling effect between adjacent cells. The state sequence given by the equation generates degraded beam pattern compared to the array factor calculation. A mathematical model of the current flow on patches of each cell which includes the coupling effect is presented. By combining this model with the particle swarm optimization technique, the optimal state sequence is derived which can generate similar gain in both directions. The sequence is tested through full wave simulation and it was confirmed that the gain difference was within 1 dB in both directions, which means that the proposed methodology shows enhanced result compared to the original modulating equation. This antenna and methodology present the possibility of generating any desired beam patterns by elaborating the mathematical model and activating various states in each cell.

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