MECHANICAL PHASE SHIFT BY MOVING A DIELECTRIC BLOCK IN THE DIVIDER FOR SINGLE-LAYER SLOTTED WAVEGUIDE ARRAYS

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1. Introduction

This paper proposes beam scan by moving dielectric blocks mechanically in the feed waveguide of single-layer slotted waveguide arrays as shown in Fig.1. Millimeter-wave antennas with beam scan are desired in various systems such as collision-avoidance car radars [1-3]. Electrical scanning is the best but mechanical one is still attractive in terms of cost, efficiency, heat-radiation and reliability if the antennas and the movable parts are light in weight and small in size. Single-layer slotted waveguide arrays [4] are planar antennas that keep high efficiency at a range of high gain even in millimeter-wave band and have simple structure suitable for mass production. This array with mechanical scan is a candidate in the above-mentioned point of view. Previously, we discussed mechanical phase shift by a movable metal plate in the power divider of the feed waveguide [5]. An amount of 86 degrees were obtained experimentally at 4GHz band, which corresponded 10-degree beam shift. However the metal plate for this phase shift was so long that the design including the adjacent coupling windows was required. In this paper, the metal plate is replaced with a dielectric block. The size of the block can be reduced to 42.3% of the length of the metal plate for equal amount of phase shift at 4GHz band. The reduction is enough for the block to be designed alone.

2. Configuration

Fig.1 shows a single-layer slotted waveguide array with phase shifters of a movable dielectric block. The feed waveguide is placed at the same layer of the radiating waveguides. It consists of cascaded π-junctions, each of which excites two radiating waveguides through a coupling window. In the conventional array without the phase shifters, the spacing of the π-junctions are set to be one guided wavelength so that they are excited in co-phase. Also, each π-junction is designed to suppress the reflection by placing an inductive post in front of the coupling window. Now, each of the phase shifters is placed between two coupling windows. The phase shifter should have reflection and be small enough not to affect the coupling of the windows. It has a two-dimensional structure uniform along the side wall. It has a metal projection at a side wall. A dielectric block is inserted and moved in the projection to give phase shift, which gives beam squint in the plane parallel to the feed waveguide.

3. Beam scan by two phase shifters at 12GHz band

Fig.2 shows a model to confirm the feasibility of beam scan by the two phase shifters at 12GHz, using WRJ-120 standard waveguides with the width a of 19.05mm. The structure is uniform along the height. The design frequency is 12.0GHz. The dielectric using for the phase shifters is polycarbonate with the dielectric constant of 2.8 and the loss tangent of $5.5\text{x}10^{-3}$. In this model, three T-junctions are used to confirm the phase and amplitude difference between the coupling windows for the feasibility instead of π-junctions in an actual co-phase fed single-layer waveguide array. The feed waveguide is designed independently from the phase shifters so that the reflection of each T-junction is suppressed and the division to all the output ports is uniform in amplitude and phase. The phase shifter is analyzed by the two-dimensional finite element method [6]. It is designed to suppress the reflection by choosing the length L properly for $W = S = a$. Fig.3 shows the reflection and the phase shifts as functions of the position p of the dielectric for L = 8.21mm. The amount of the phase shift is about 90 degrees and the reflection is below –20dB for the full range of p. The phase shift is rapidly changed around p = 8mm. This comes from the resonance of the dielectric.

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4. Experimental results

Experimental results are shown at 12.15GHz. The discrepancy between the calculations and the experiments in frequency would be due to errors in the dielectric constant and the fabrication. The full structure of the model is analyzed by the finite element method simulator Ansoft HFSS. Fig.4 shows the phase difference between the adjacent coupling windows as a function of the dielectric position *p*. The agreements between the calculations and the experiments are good. About 90-degree phase difference can be confirmed over the full range of *p* between 0.0 - 19.05mm. Fig.5 shows the overall reflection as a function of *p*. The measured reflection is maximized up to −9dB for p = 12mm. It should be reduced around this value of *p*. Fig.6 shows the dividing amplitudes to all the output ports as a function of *p*. The tendency of each output port agrees well in the calculation and the experiment. The difference among the output ports is the maximum of 3dB for p = 14mm. Fig.7 shows the loss of the 12GHz band model as a function of *p* including the two dielectric blocks. For the comparison, the result of a 4GHz band model using a dielectric clock is added. The maximum loss is 0.8dB in the calculation and 1.2dB in the experiment near their resonance for p = 12mm. The loss mainly comes from the dielectric. Lower-loss material should be used to reduce the dielectric loss. Fig 8 shows the radiation patterns from the three output ports #3 - #5 as apertures embedded in a large ground plane, as a function of *p*. The main beam is shifted by 11 degrees over the full range of *p*. Grating lobes are observed due to a window spacing of $1.32\lambda_0$. However, in the actual waveguide array, they can be suppressed by the spacing of $0.66\lambda_0$ in the radiating waveguides using π-junctions and a taper amplitude distribution along the feed waveguide.

5. Conclusion

The authors have proposed the beam scan by moving dielectric blocks mechanically in the feed waveguide of single-layer slotted waveguide arrays. For the feasibility, a model using the two phase shifters is designed and fabricated with three radiating apertures at 12GHz band. 90-degree phase difference between the adjacent windows gives 11-degree shift of the main beam.

References

[1] D.M.Stokero and N.P.Morene, “Automotive radar manufacturing-driving cost down,” Workshop on Automotive Millimeter-Wave Radar Systems, European Microwave Conf., 2000.

[2] Y.Asano, “Millimeter-wave holographic radar for automotive applications,” Microwave Workshop Digest, WS6-4, Microwave Exhibitions, 2000.

[3] S.Chen, K.Suzuki, T.Muramoto, Y.Ara and R.Iwata, “Micromachined RF switch,” Proc. IEICE Genl.Conf., B-1-171, Mar.1999.

[4] N.Goto, “A waveguide-fed printed antenna,” IEICE Tech. Rept., AP89-3, 1989.

[5] M.Higaki, J.Hirokawa and M.Ando, “Mechanical phase shifting in power divider for single-layer slotted waveguide arrays,” IEICE Trans. Commun., vol.87, no.2, pp.310-316, Feb.2004.

[6] G.Pelosi, R.Coccioli, S.Sellsri, “Quick Finite Elements for Electromagnetic Waves,” Artech House, 1998.

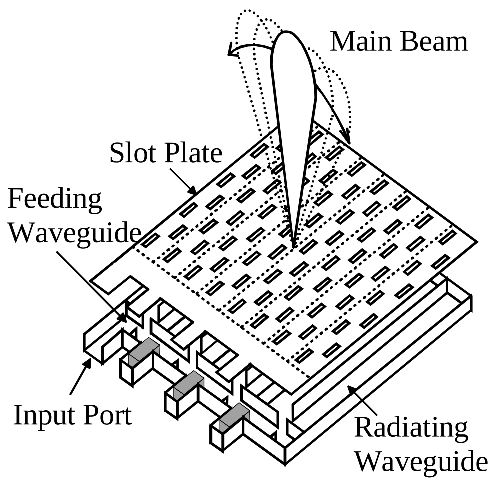

Fig.1 single-layer slotted waveguide array with phase shifters of a movable dielectric block

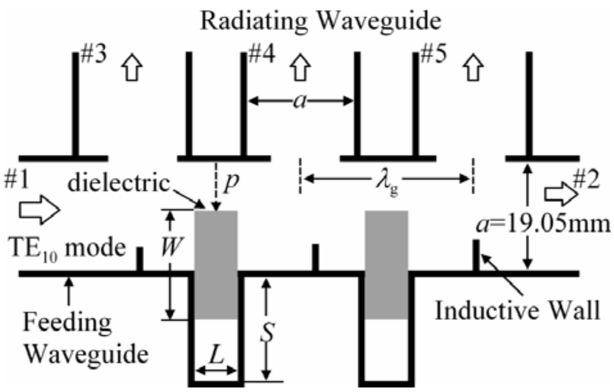

Fig.2 Model using two phase shifters

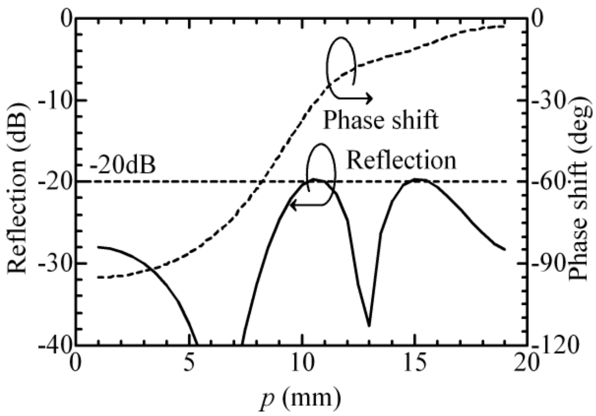

Fig.3 Calculated reflection and phase shift as functions of the dielectric position *p*

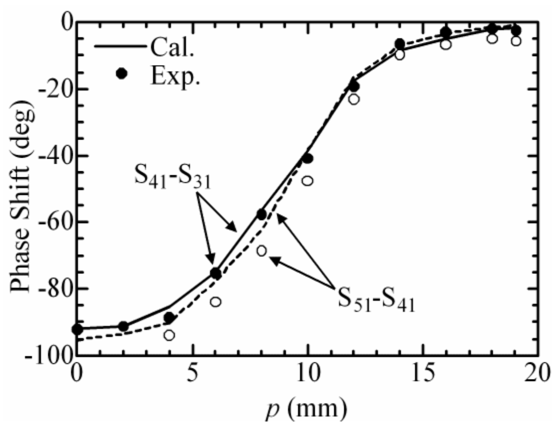

Fig.4 Phase difference as a function of the dielectric position *p*

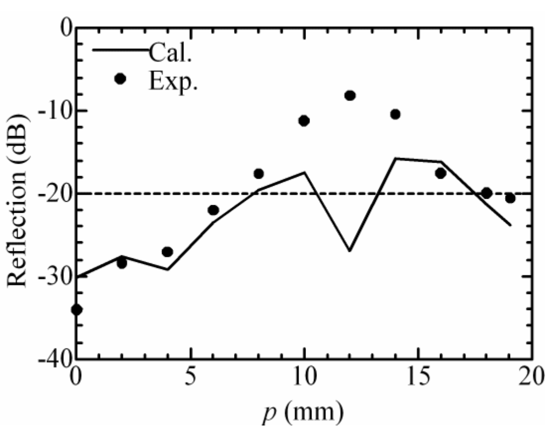

Fig.5 Reflection as a function of the dielectric position *p*

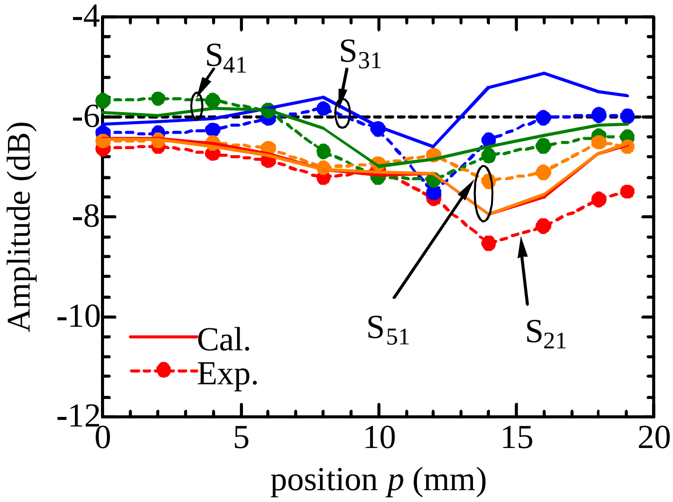

Fig.6 Divided amplitude as a function of the dielectric position *p*

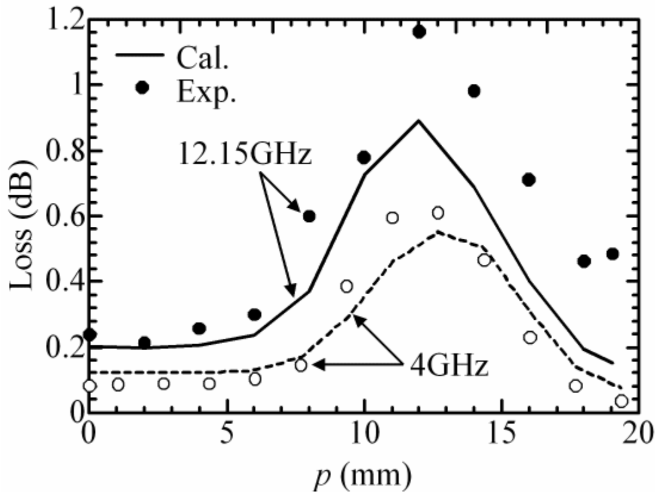

Fig.7 Loss as a function of the dielectric position *p*

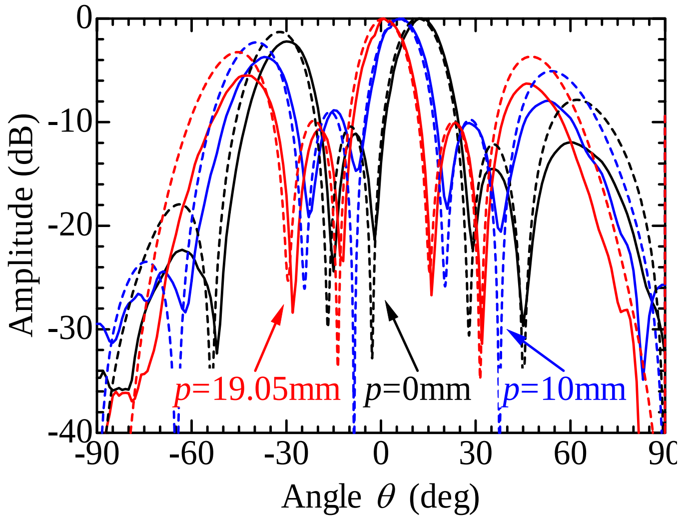

Fig.8 Radiation pattern as a function of the dielectric position *p*
(Dotted lines: calculations, solid lines: experiments)