Design of a steerable reflect-array antenna with semiconductor tunable varactor diodes

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Abstract

The demonstrator of a steerable reflect-array antenna was designed as a system of dipoles loaded by varactor diodes. The microwave response of a dipole loaded by varactor has been simulated in closed form based on equivalent circuit approach. The circuit analytical model has been verified by the full-wave analysis. Change of the varactor capacitance in the range of 0.3 – 1.3 pF was provided by biasing voltage 0 – 20 V. The array consists of 20 dipoles structured as two parallel lines. The operational frequency is 11 GHz, the length of the dipole is 9.2 mm, spacing between dipoles is 18 mm. The double-side metallized PTFE with $\varepsilon = 2.8$ and thickness of 1 mm was used as a substrate. Dipole structure was manufactured by a photolithographic process and formed with surface mounted varactor diodes. The radiation pattern of the array is characterized by the width of the main beam $\approx 8^{\circ}$, the side lobe level $-(12 \div 20)dB$, the steering range $\pm 15^{\circ}$. Control voltage was set manually with variable resistors separately for each varactor. The fine alignment of the control voltage for each varactors turned out to be very important. Inherited data are used for correction of the operational principle of a varactor steerable antenna controller.

Introduction

The reflect-array antennas are being studied many years and some theoretical and experimental results have been obtained [1-3]. The possibility to obtain an electron steering of the radiation pattern of such an antenna is currently under investigation [4, 5]. The goal of this paper is to discussed an experimental realization of a steerable reflect-array antenna demonstrator designed as a system of dipoles loaded by varactor diodes. The GaAs varactors MA46H070 produced by MACOM Inc. were tried. Control voltage applied to each varactor in the array should provide the phase shift along the dipole structures, which is necessary for transformation of a spherical phase front of a prime radiator into the plane phase front with the required declination. One should simulate the distribution of the phase shift of reflection coefficient of each dipole and find the dependence of the phase shift on the biasing voltage applied to the varactor loading the dipole. A set of error sources complicates solution to the problem. The following errors should be taken into account. 1) Incorrectness in simulation of the phase shift of reflection coefficient as a function of the dipole sizes and value of the varactor capacitance. 2) Dispersion of the dependence of the varactor capacitance on the applied biasing voltage. 3) Fabrication errors in dimensions of the design components.

In order to overcome difficulties mentioned above, the experience of designing and examination of different version of steerable reflect-array antenna should be accumulated and used for developing the design procedure.

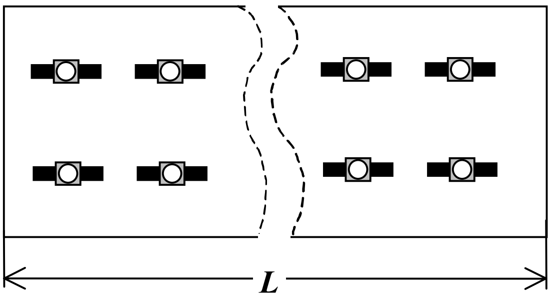

Fig. 1. Structure of the array under investigation. The array consists of 20 dipoles structured as two parallel lines. The total length L = 200 mm.

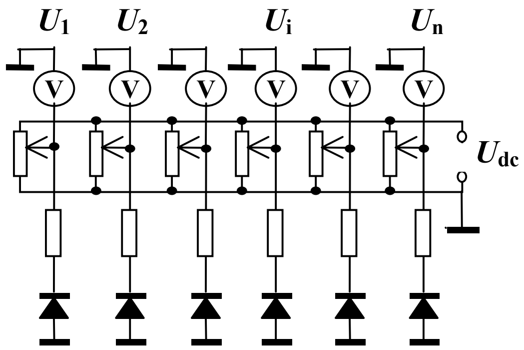

Fig. 2. Scheme for formation of the control voltages. The voltages applied to varactors are separately registered.

Design of the demonstrator

In Fig.1 structure of the array under investigation is shown. The array consists of 20 dipoles structured as two parallel lines. Spacing between lines and spacing between dipoles in the lines are 18 mm. Each dipole is loaded by a tunable varactor. The dipole length is 9.2 mm, The doubleside metallized PTFE with ε = 2.8 and thickness of 1 mm was used as a substrate. A *dc-rf* filter and *dc*-biasing strip lines are arranged for each dipole. Fig. 2 shows the equivalent diagram of the bench, which was used for formation of the control voltages. The control voltages were set manually with variable resistors separately for each varactor. The fine alignment of the varactor tuning was find to be very important. That can be explained by a sharp dependence of the phase of the dipole reflection coefficient on value the biasing voltage. Fig. 3 illustrates this dependence, which was simulated for the dipole considered. Fig. 4 shows the derivative of the reflection coefficient phase with respect to the biasing voltage as a function of the biasing voltage. One can see that at the section of curve (Fig. 3) with the highest slope, the setting the phase shift with accuracy $\pm 45^{o}$ requires the accuracy of setting the biasing voltage better than

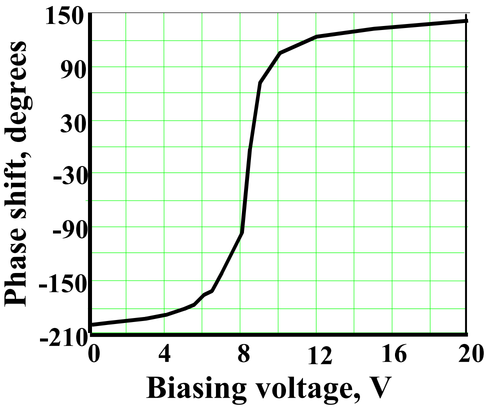

Fig. 3. Dependence of the phase of the dipole reflection coefficient on biasing voltage

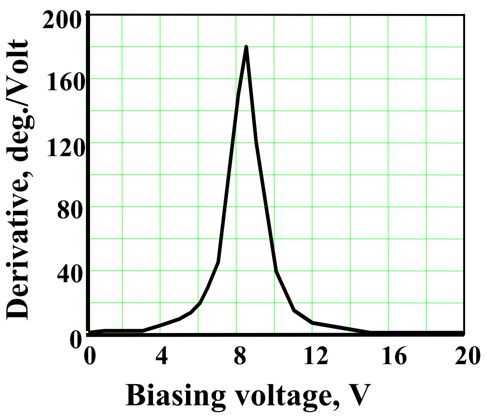

Fig. 4. Derivative of the reflection coefficient phase with respect to the biasing voltage

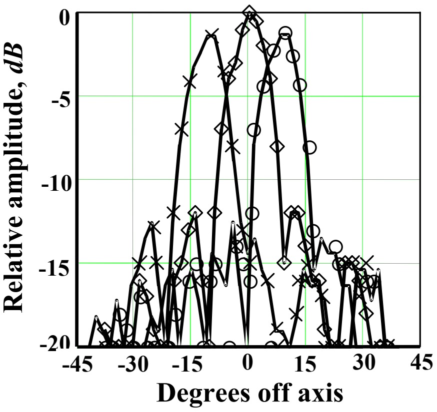

Fig. 5. Radiation pattern of the steerable reflect-array (three positions).

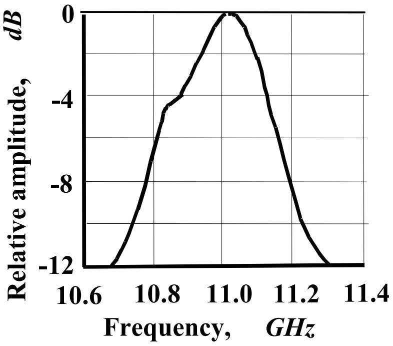

Fig. 6. Amplitude-frequency response of the steerable reflect-array

± 0.25 V. That relates not only to the accuracy of the biasing voltage control, but to repitability of the varactor Volt-Farad characteristics.

Some experimental results

The prime radiator was placed in a distance from the surface of the array of 100 mm. The open end of a rectangular waveguide with the transverse section 23x5 mm^2 was used as the prime radiator.

The required phase distribution along the array was simulated in closed form based on equivalent circuit approach. The adequacy of the circuit analytical model has been verified by the full-wave analysis. The simulation of the required phase distribution was followed by the simulation of distribution of the biasing voltage applied to all varactors.

Performance of the radiation pattern of the array at the frequency 11 GHz is shown in Fig. 5. Three positions of the main beam are shown: -10^o; 0^o; $+ 10^o$. The amplitudes of the radiation pattern in all positions are practically the same. While measuring the radiation pattern, the biasing voltage distribution was slightly corrected to obtain maximum of the signal.

The gain of the antenna was not measured, because the efficiency of the prime radiator had not been optimized.

Fig. 6 gives the amplitude-frequency response of array in the center position of the main beam. The frequency band of the antenna is about 2% at the level of –3 *dB*. Such a narrow frequency band can be referred to a high quality factor of a resonant tank formed by the dipole and the tunable varactor. It may be assumed that the reactive parameters of the pair dipole-varactor can be optimized and the frequency band can be extended.

Conclusion

A steerable reflect-array antenna demonstrator was experimentally realized. The results of the demonstrator investigation are in agreement with the theory of the steerable antenna arrays [6, 7]. That gives possibility to make a confident conclusion that the steerable reflect-array antenna based on application of the tunable varactors can be designed and manufactured. Such an antenna can be offered as a cheap version of steerable antenna for a mass production.

References

1. D. C. Chang and M. C. Huang, *IEEE Trans. Antennas Propagat.*, vol. 43, Aug. 1995, pp. 829–834.
2. D. Pilz, W. Menzel, *Electron. Lett.,* Vol. 34, No. 9, April 1998, pp. 832 – 833
3. L. Boccia, F. Venneri, *et al*, *Proc. IEEE Antennas Propagat. Soc. Int. Symp.*, vol. 3, 2002, pp. 132–135.
4. R. Romanofsky, J. Bernhard, et al., *IEEE MTT-S*, 2000, 00TH 1D_1.
5. D. F. Sievenpiper, J. H. Schaffner, *et al., IEEE Trans. Antennas Prop.*, vol. 51, Oct. 2003, pp. 2713-2723
6. C.A.Balanis, “Advanced Engineering Electromagnetics”, *John Wiley & Sons*, 1989.
7. O.G. Vendik, M.D. Parnes, “Antennas with electrical scanning (introduction to theory), Ed. by L.D. Bakhrakh (in Russian), Moscow, *Science-Press*, 2002.

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