INVESTIGATION OF THE RECONFIGURABLE ANTENNA WITH A SET OF PIN DIODES

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Abstract

This work presents the design of reconfigurable antenna based on a leaky-wave microstrip line operating on a higher order mode. The antenna structure comprises a set of discrete PIN diodes, modeled in electromagnetic simulation by its equivalent circuit. Relation between the number of diodes and antenna performance is discussed in details.

Keywords: reconfigurable antennas, p-i-n diodes, leaky wave antennas, microstrip antennas

1. Introduction

The evolution of radiocommunication systems makes the components of radio devices increasingly complex and sophisticated. Often components are designed to realize various functions depending on the state of the device, installed software and other circumstances. Antenna system is indispensable part of a radiocommunication system, however, until now it was rather difficult to make it such flexible like other components. Recent antenna designs techniques enables electronically controlled change of antenna's characteristics.

Recently, many concepts of the reconfigurable antenna structures were proposed. Its common feature is the application of some switching elements, i.e. PIN diodes or MEMS switches. Each type of switching element has its advantages and drawback. The PIN diodes are elements having many qualities: very small dimensions, easy implementation to the structure, providing steering signal just common with RF signal, available and cheap.

2. Reconfigurable Antenna Design

Reconfigurable antenna discussed in this paper is based on a microstrip line in which the higher order mode is excited [1]. The propagation parameters of the microstrip line and, consequently, the operating frequency band of the antenna depend strongly on the width of the line. Fig. 1 presents the structure of reconfigurable leaky-wave antenna proposed by authors of this paper. It consists of main aperture fed by microstrip 50 Ω line and expanding aperture. The expanding aperture is turned on and off by a set of PIN diodes mounted parallel in the slot between apertures. Therefore it is possible to change the effective width of the aperture. This results in significant shift of the propagation parameters in frequency (Fig. 2, [2]), and consequently the operating frequency band of the antenna is switched.

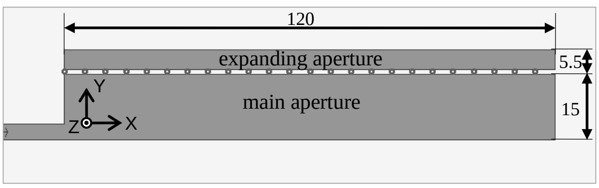

Fig. 1. The structure of the reconfigurable leaky-wave antenna

It is worth to notice that, as opposed to many reconfigurable structures based on simple patch antennas, the presented reconfigurable leaky-wave antenna has quite high directivity.

The experimental model of antenna with 24 PIN diodes has been manufactured and measured (Fig. 3). Experimental results are presented in [3]. This work presents further investigation of the reconfigurable antenna design. The results have been received from electromagnetic simulations based on FDTD method.

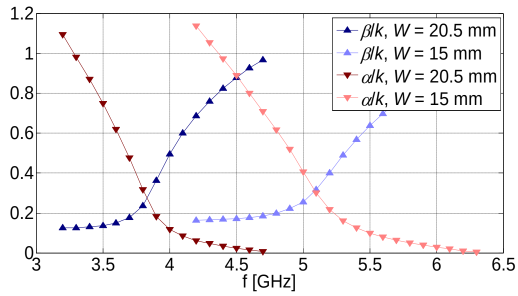

Fig. 2. Propagation parameters of the first higher order mode in the designed microstrip structure

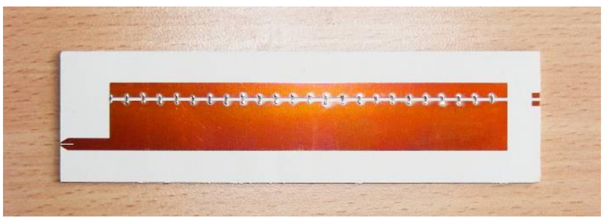

Fig. 3. The experimental model of the designed antenna

3. Exciting of the Expanding Aperture

The number of 24 PIN diodes has been chosen in order to provide proper field excitation in the expanding aperture. However, alternative numbers of diodes have been also considered. The number of diodes has an influence on the field distribution in the apertures as well as on the antenna efficiency and gain.

The electromagnetic field distribution in the structure has an impact on the obtained reflection coefficient. Figs. 4 and 5 present reflection coefficient of antenna with N uniformly distributed diodes for "off" and "on" state, respectively. It was expected that antenna operates in 5.1-5.4 GHz frequency range in "off" state (Fig. 4), and in 3.7-3.95 GHz frequency range in "on" state (Fig. 5). However, it can be observed, that the operational frequency bands depend on the number of diodes used. In "off" state the operational frequency bandwidth decreases with the increase of N. It results from the capacitance of diodes, giving parasitic coupling between apertures and therefore causing undesirable exciting of the expanding aperture. In "on" state – contrary – the operational frequency band decreases as N is decreased. If the number of diodes is few, the expanding aperture cannot be excited effectively.

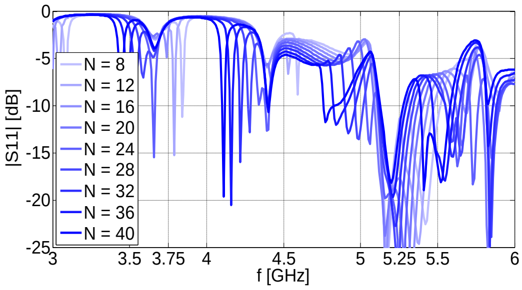

Fig. 4. Reflection coefficient for various number of diodes in the structure, diodes switched off

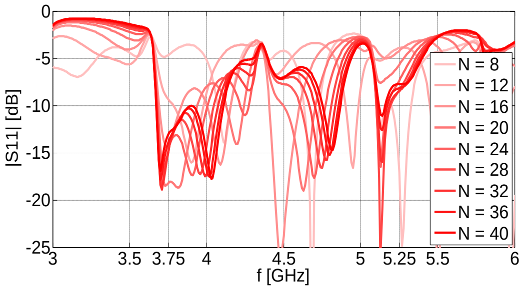

Fig. 5. Reflection coefficient for various number of diodes in the structure, diodes switched on

4. Efficiency Analysis

When designing the reconfigurable antenna it is important to determine the RF power losses in the structure, especially in switching elements. Fig. 6 presents relative power losses in the antenna for various values of N at frequencies taken from operational frequency band for both antenna states: f_{off} = 5.25 GHz, f_{on} = 3.75 GHz. Three types of RF losses are marked out: reflection loss, diodes' losses and the third – losses in substrate and metallization, ('volume loss'). The remaining power is radiated into the space. Fig. 7 presents absolute radiation efficiency.

Other sources of losses are recognized as negligible. Losses in dielectric and metallization are quite low because RO3003 used as a substrate is well recognized as quality substrate. Reflection losses are insignificant, except for the "on" state of antenna comprising small number of diodes.

The losses in diodes are the most significant. High power dissipation appears only at "on" states and is caused by series impedance of diodes. Increasing the number of diodes reduces losses – this relates to the parallel connection of more elements with the same series impedance. It can be noticed that for the "on" state at least 16 diodes are necessary to obtain proper electromagnetic excitation of expanding aperture (low reflection losses), further increasing the diodes' number makes losses in diodes lower.

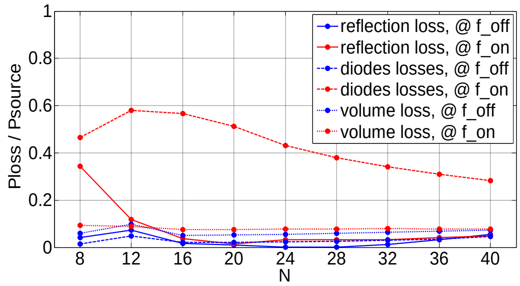

Fig. 6. Relative power losses in the antenna vs number of diodes

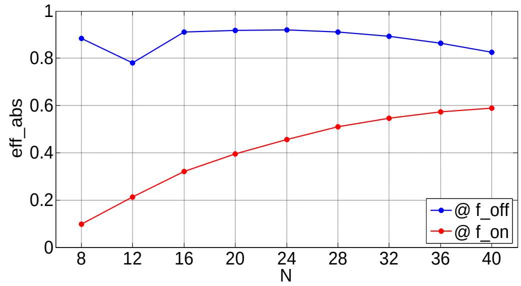

Fig. 7. Absolute radiation efficiency vs number of diodes

Fig. 7 shows that the antenna efficiency in "on" state grows when increasing the diodes' number. However the large number of diodes is not optimal due to narrowing the frequency band in "off" antenna state.

It may by observed in Figs. 8 and 9 that the main beam direction changes depending on the diodes' number. It indicates that the propagation parameters of the microstrip line depend on diodes' number. The main beam direction depends on the frequency, and thus it is possible to adjust the operating frequencies for fixed antenna design in order to obtain the same main lobe direction in both antenna states. On the other hand, it is possible to adjust the antenna design for fixed operating frequencies in order to obtain the same.

It can be noticed that the main lobe level is lower in "on" state. In Fig. 10 it can be seen that switching on and off causes 4 dB change of the maximal gain of the antenna provided with 24 diodes. Two facts are the main cause of this effect: lower antenna efficiency in "on" state, and, the minor one, longer wavelength at lower frequencies.

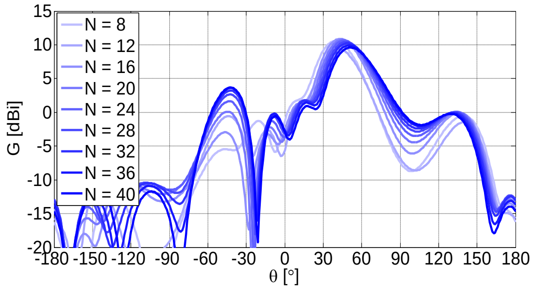

Fig. 8. Absolute antenna gain for various number of diodes in the structure, diodes switched off @ 5.25 GHz, XZ plane

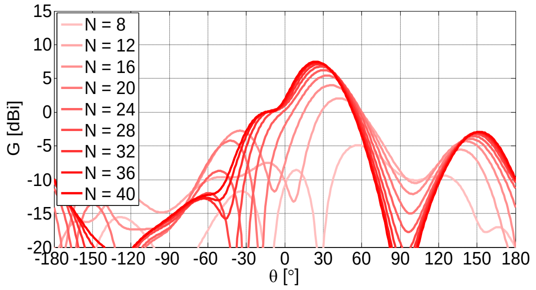

Fig. 9. Absolute antenna gain for various number of diodes in the structure, diodes switched on @ 3.75 GHz, XZ plane

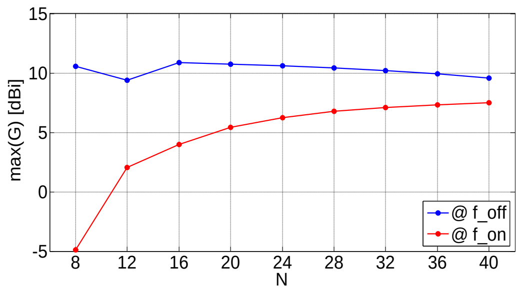

Fig. 10. Maximal absolute gain vs the no. of diodes

5. Distribution of Power Dissipation in Particular Diodes

Electromagnetic simulations give an opportunity to determine normalized power dissipation in particular diodes (Fig. 11, *d* stands for diode's position). It can be clearly noticed that power dissipation in "on" state is much higher than in "off" state. The distribution of power dissipated in subsequent diodes corresponds to the electric field distribution along the slot between apertures. That observation leads to a conclusion that a change of the uniform distribution of the diodes on the aperture is a possible way to reduce the losses. Such experiment is planned for future work.

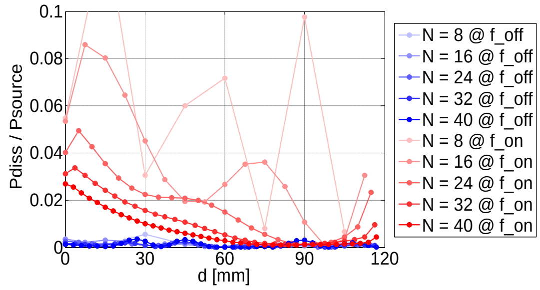

Fig. 11. Distribution of the power dissipation in particular diodes for various number of diodes in the structure

6. Conclusions

The design of reconfigurable antenna based on leaky-wave microstrip line operating on a higher order mode has been discussed. The detailed analysis of dependence of antenna performance on diodes' number is shown. The conclusions are as follows: increasing the number of diodes results in narrowing the higher frequency band (in "off" state), decreasing the number of diodes results in narrowing the lower frequency band (in "on" state). For the antenna discussed in this paper 24 diodes seems to be appropriate compromise. Increasing the number of diodes results in higher antenna efficiency in "on" state. It is possible (in certain boundaries) to adjust the operating frequencies for fixed antenna design, or adjust the antenna design for fixed operating frequencies, in order to obtain the same main lobe direction in both antenna states. The space distribution of power dissipation in particular diodes is not uniform, hence nonuniform diodes distribution might be considered in order to minimize total RF losses in the structure.

Acknowledgments

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