CHARACTERIZATION AND MINIMIZATION OF MUTUAL COUPLING BETWEEN NLC-FED SLOT ANTENNAS

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ABSTARCT - Mutual coupling between both single and twin slot antennas fed by non-leaky coplanar (NLC) waveguides with conductor backing is characterized rigorously for the first time. While there is pronounced mutual coupling (about -12 dB) between two single slots separated by $\lambda_0/2$, we show that by employing an optimized twin-slot configuration, it is possible to reduce significantly the coupling level to below -30 dB over a 15% bandwidth, making this unidirectional radiator an attractive candidate for millimeter-wave imaging arrays.

INTRODUCTION

CPW-fed slot antennas have been widely used in recent years in a number of applications such as quasi-optical mixers [1], integrated oscillators [2] and focal plane imaging arrays [3]. These uniplanar structures are of particular interest at millimeter-wave frequencies, due to several advantages including ease of shunt connection of devices, free of via holes, greater tolerance in dimensions as well as lower frequency dispersion in comparison with microstrip-based structures.

Two major problems, however, exist in relation with these planar slot antennas. The first is its bi-directional radiation property, which will lower the antenna efficiency if not compensated properly. The second is the excitation of surface wave modes, which becomes a serious problem at higher frequencies where it is difficult to make the substrate electrically thin. To solve these problems, the extended hemispherical substrate lens approach [4] and the multilayer dielectric substrate approach [5] have been proposed, and implemented successfully for several millimeter-wave applications. On the other hand, a new type

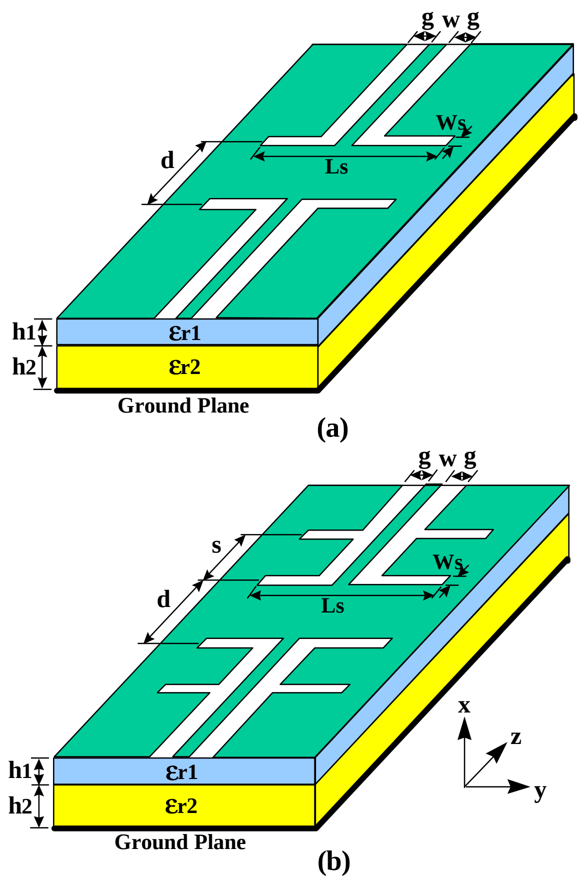

Fig. 1. (a) Single-slot and (b) Twin-slot antennas fed by non-leaky coplanar (NLC) waveguide with conductor backing.

of uniplanar slot antenna, which is based on the recently proposed non-leaky coplanar (NLC) waveguide structure with conductor backing [6], was demonstrated successfully in the form of an active integrated oscillator [7]. The intrinsic uni-directional radiation of this NLC-fed slot antenna makes itself a very promising candidate for several

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millimeter-wave systems such as focal plane imaging arrays.

An important issue which has not been addressed yet in relation with these NLC-fed slot antennas is the mutual coupling within an array environment. In this paper we conduct a detailed study of the coupling between both single and twin slot antennas based on the NLC structure. While a relatively strong coupling has been found between two single NLC-fed slots due to the existence of the zero-cutoff TM_0 surface wave, we show that it is possible to reduce this mutual coupling significantly by employing a twin-slot configuration in an optimized NLC structure. Another advantage of the twin-slot approach is that the E- and H-plane radiation patterns are more symmetric than that of a single-slot, which is a strongly desired property in most quasi-optical applications.

FDTD ANALYSIS OF NLC-FED SLOT ANTENNAS

Fig. 1 shows the geometries of the NLC-fed slot antennas we have studied in this paper. The non-leaky coplanar (NLC) waveguide is realized by employing a double-layer susbstrate and choosing a proper combination of the thickness and dielectric constant for the two layers. The resultant waveguide structure is non-leaky even if a conductor backing exists [6]. The ground plane not only results in a uni-directional radiator, both also improves the mechanical strength and heat handling capability of the structure.

To characterize the mutual coupling between the slot antennas, we employ the FDTD method, which has been applied successfully in our previous analysis of CPW-fed slot antennas on layered dielectric substrates [8]. To confirm the accuracy of the FDTD simulation results, we compare the complex input impedance of the single NLC-fed slot, which has been analyzed using the spectral domain approach (SDA) in [7]. As shown in Fig. 2, the two results are basically identical, showing a wide range of low impedance around the second resonant frequency (6GHz) of the radiating slot.

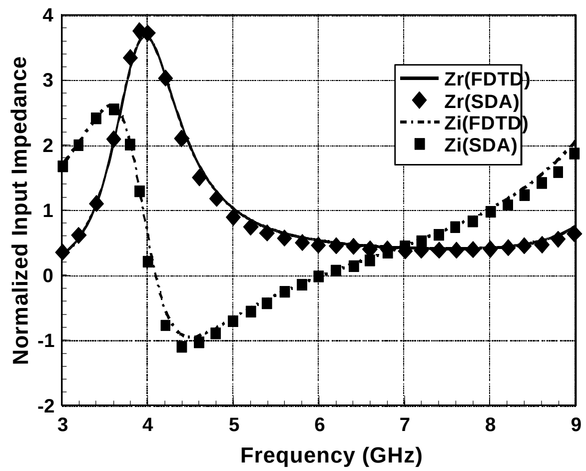

Fig. 2. Comparison of FDTD and SDA results of the complex input impedance of an elementary NLC-fed slot antenna. Dimensions are: ε_{r1} = 10.8, ε_{r2} = 2.2, h_1 = 50 mil, h_2 = 125 mil, w = 39 mil, g = 78 mil, w_s = 78 mil, L_s = 827 mil.

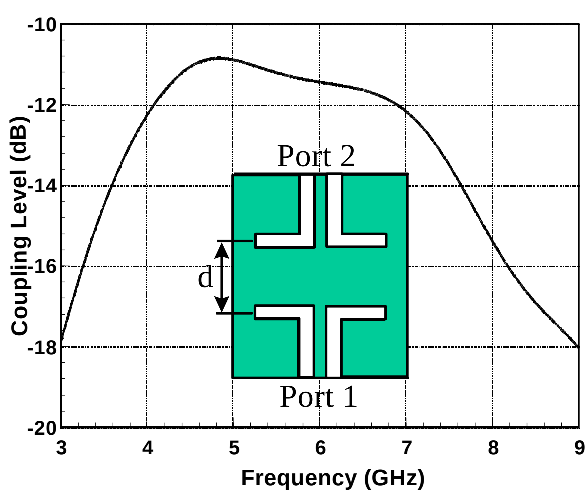

Fig. 3. FDTD simulation results of the mutual coupling level between two NLC-fed single-slot antennas separated by $\lambda_0/2$ (d = 25 mm) at 6 GHz in the broadside. Other dimensions are the same as shown in Fig. 2.

MUTUAL COUPLING BETWEEN SINGLE- AND TWIN-SLOT ANTENNAS

Fig. 3 shows the FDTD simulation result of mutual coupling ($|S_{21}|$) between two NLC-fed single-slot antennas separated by $\lambda_0/2$ at 6 GHz. A relatively high level of mutual coupling (-11.4 dB) is observed at the center frequency, due to the excitation of the TM_0 surface wave mode. In order to reduce this mutual coupling, we propose the cascade-connected twin-slot configuration as shown in Fig. 1(b). To ensure in-phase feeding of the two slots, their separation (s) should be equal to one guided wavelength of the connecting NLC waveguide. Meanwhile, s should also be close to half wavelength of the TM_0 mode so that the surface waves originated from the two slots can be effectively canceled. These two requirements can be satisfied simultaneously if $\beta_{TM0} = \beta_{NLC}/2$, where β_{TM0} and β_{NLC} are the propagation constant of the TM_0 mode and the NLC mode, respectively.

In conventional CPW structures, it is difficult to realize the above optimal phase cancellation effect without efforts such as bending the connecting CPW. However, the NLC structure in Fig. 1 provides some additional dimensions of freedom for this purpose. One approach is to use a smaller permittivity material for the lower substrate. The non-leaky property of the structure can be preserved since decreasing ε_{r2} will further reduce the propagation constant of the parallel plate mode while having little effect on the NLC mode. Meanwhile, it is observed that the propagation constant of the TM_0 mode (β_{TM0}) also decreases when ε_{r2} becomes lower, as shown in Fig. 4. For this particular structure, the condition $\beta_{TM0} = \beta_{NLC}/2$ can be satisfied when ε_{r2} is close to 1, indicating that an optimal phase cancellation of surface waves is possible.

Fig. 5 compares the FDTD simulation results of the mutual coupling between two single-slots and two twin-slots based on the optimal design approach mentioned above. The dielectric constant of the lower substrate (ε_{r2}) has been simply chosen as 1 where β_{TM0} is close to $\beta_{NLC}/2$. As has been expected, the mutual coupling for the twin-slot case has been reduced significantly, which is below -30 dB over a 15% (5.8 ~ 6.7 GHz) bandwidth. In contrast, the mutual coupling between two single-slots with identical broadside spacing (d = $\lambda_0/2$) remains relatively high, which is above -14 dB within the same frequency range.

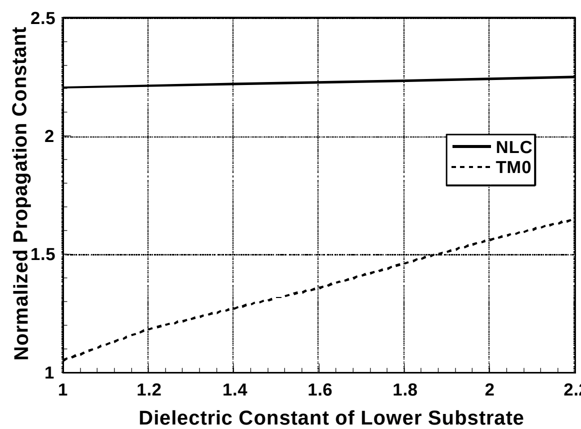

Fig. 4. Normalized propagation constants of the NLC mode and TM_0 mode with respect to different dielectric constant of the lower substrate (ε_{r2}) in the NLC structure.

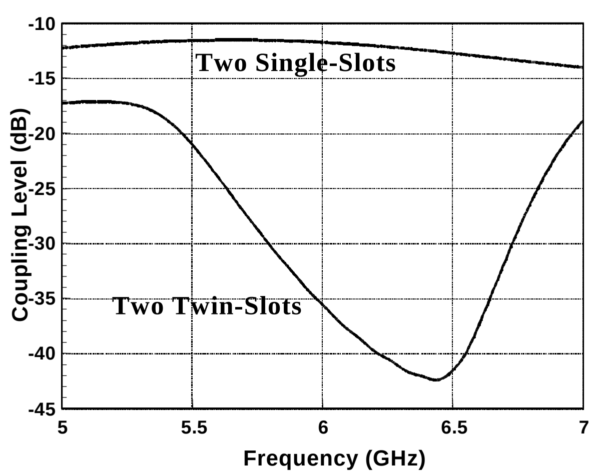

Fig. 5. Comparison of mutual coupling between two single-slots and two twin-slots in the optimized

NLC structure. The mutual coupling level between the twin-slots is below -30 dB over a 15% bandwidth.

CONCLUSIONS

In conclusion, we have shown that the optimized NLC-fed twin-slot antenna with conductor backing could achieve extremely low mutual coupling in an high-density array environment, making itself a very attractive candidate as feeding element for millimeter-wave focal plane imaging arrays. The new antenna structure can be easily implemented in our previous design of a 60 GHz imaging array system [3].

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