UC-PBG ANTENNA ON THICK DIELECTRIC SUBSTRATE

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Automotive systems for pre-crash detection will operate at frequencies around 77 GHz. In order to keep costs low, a full integration of the radar system including the antenna into semiconductor chips is advantageous, but creates new problems like strong coupling to substrate modes. In this paper we analyse an active antenna design with reduced substrate mode excitation due to periodic surrounding and present a system identification approach for improving the simulation speed.

Introduction

The integration of both an oscillator and the antenna onto the same semiconductor chip has the advantage of reducing both size and costs for such systems and inherently eliminates interconnection problems.

Silicon millimeterwave integrated circuits (SIMMWICs) can be realized for frequencies up to above 100 GHz [1]. The use of IMPATT diodes as the active element allow to realize integrated oscillator and antenna structures. The IMPATT diode is embedded into a planar structure that serves as resonator for the oscillator and also as antenna. In designing such an active antenna circuit the main design goals are to achieve low impedance matching to fulfill the oscillation condition of the IMPATT diode and to reduce the excitation of substrate waves which may reduce the radiated power dramatically.

The chip substrate height of 525 µm with a permittivity of $\epsilon_r = 11.7$ at the operational frequency $f = 60$ GHz strongly excites substrate modes, namely the TM_0 mode with no cut-off frequency and the TE_1 mode with $f_c = 43.7$ GHz. [2]

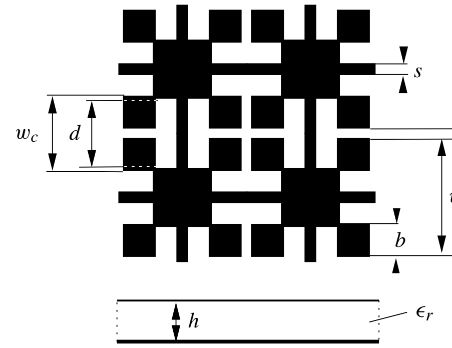


Figure 1: Geometry of UC-PBG unit cell: $a = 454$ µm, $w = 416$ µm, $s = 38$ µm, $b = 114$ µm, $d = 246$ µm, $h = 525$ µm, $\epsilon_r = 11.7$

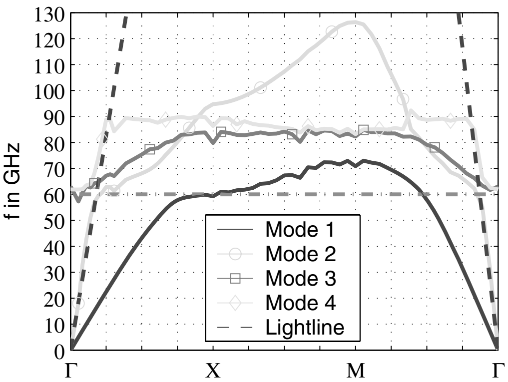


Figure 2: Band diagram

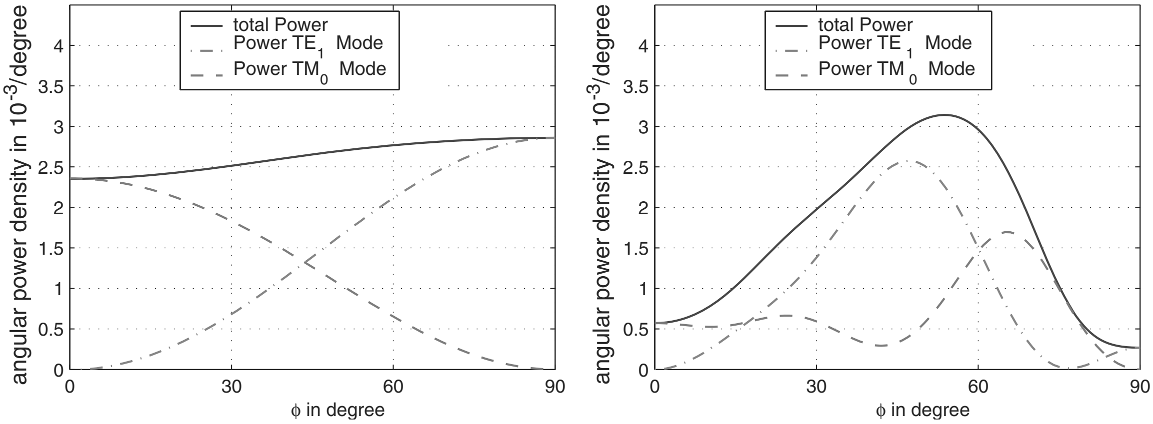
Antenna Design

When using thick dielectric substrates, the radiation generated by small dipoles is nearly completely trapped in the substrate waves, thus giving a a maximum gain of $G_{\max} < -50$ dB. In order to improve the antenna gain, a uniplanar compact photonic bandgap (UC-PBG) [4, 5] structure surrounding a coplanar stripline resonator is proposed. The coplanar strip-line resonator serves as the resonator of the IMPATT oscillator when the IMPATT diode is inserted at the feed point. Furthermore the resonator couples the millimeterwave signal to the UC-PBG structure. The resonator radiates primarily into substrate modes; this trapped power is then converted into the free space radiation by the UC-PBG structure.

In this work the matching of the IMPATT diode to the integrated resonator and antenna structure and the improvement of the radiation efficiency by the use of the UC-PBG structure are investigated. Various tools for full-wave modelling of the planar structure are used. The complex planar structure requires an extreme computational effort. To meet with this demand a time-domain electromagnetic field solver has been combined with signal identification postprocessing. The effect onto the antenna impedance to the diode of the mutual interaction of the stripline resonator to the UC-PBG structure is analyzed in this contribution and accelerated using a system identification approach.

UC-PBG Analysis

The angle dependent excitation of the TM_0 and TE_1 mode by a coplanar stripline resonator is depicted in fig. 3. $P_{\text{substrate}}$ is the total power emitted into the substrate obtained by integration in the near-field, as shown in fig. 4. One can observe that the power emitted into the resonator's principal axes is largely reduced and therefore radiated into



(a) coplanar stripline resonator only

(b) coplanar stripline resonator with UC-PBG structure

Figure 3: Angular dependence of substrate mode excitation $\frac{1}{P_{\text{substrate}}} \frac{\mathrm{d}P_{\text{substrate}}}{\mathrm{d}\phi}$ in the near field of the antenna. Simulation setup shown in fig. 4

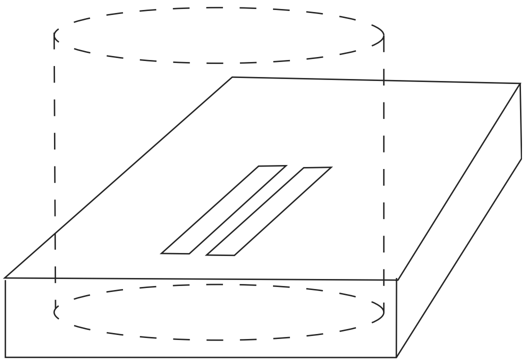


Figure 4: cylinder barrel is the area of integration for $P_{\text{substrate}}$ in fig. 3

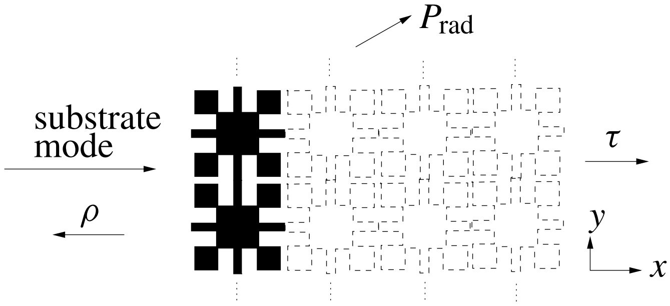


Figure 5: simulation set-up of fig. 6

free-space, as the maximum Gain increases to $G_{\text{max}} = -8\,\text{dB}$. Thus in the band diagram (computed with HFSS, see fig. 2), mainly the Γ–X section is of interest which describes normal incident waves. Neglecting leaky waves, a bandgap is observable at 60 GHz.

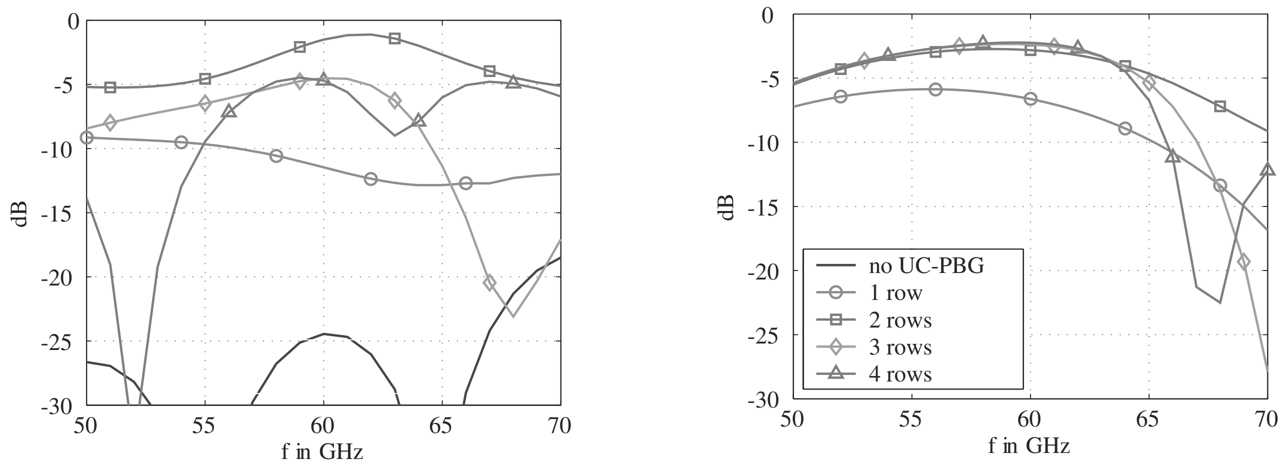
In fig. 6 the computed reflection coefficient ρ for a plane substrate wave incident in x-direction of a truncated structure as depicted in fig. 5 is shown. As a result, the reflection of the substrate modes is optimal for two and three rows of unit cells.

A coplanar stripline resonator embedded in a UC-PBG structure with three rows of unit cells is therefore used for the integrated antenna as shown in fig. 7. The total size of the planar structure is 3150 µm × 2700 µm, the stripline resonator consists of two metal strips of 850 µm × 20 µm size, the gap width is 20 µm. The input impedance of the planar structure to be connected with the diode is $Z = (-40 - \mathrm{j}160)\,\Omega$. This fits well with the oscillation conditions for an IMPATT oscillator [8]. The impedance at the point of the diode of the measurement and two simulations tools are given in fig. 9, matching well to the diode impedance of $Z = (-40 - \mathrm{j}160)\,\Omega$. The simulations have been performed using FEKO and CST MWS.

System Identification

Time domain simulations showed to give convergent results only if excited by a bandpass excitational pulse. In addition at the feed point of the diode a fine discretization is necessary, limiting the maximum stable time step and large simulation times, even when using an autoregressive (AR) filter. Therefore a system identification approach using the Matrix Pencil Method [7] with the order of pole model $M = 10$ was used to reduce simulation time.

In fig. 8 the S-parameter of the antenna using obtained by using the built-in AR filter of CST MWS and MPM is shown. Stability is achieved after 0.71 ns in comparison to 1.42 ns using the AR approach, contributing in 200 % simulation performance increase.



(a) TM_0 reflection

(b) TE_1 reflection

Figure 6: reflection parameters of different UC-PBG structures, truncated in the direction of propagation. Simulation setup shown in fig. 5

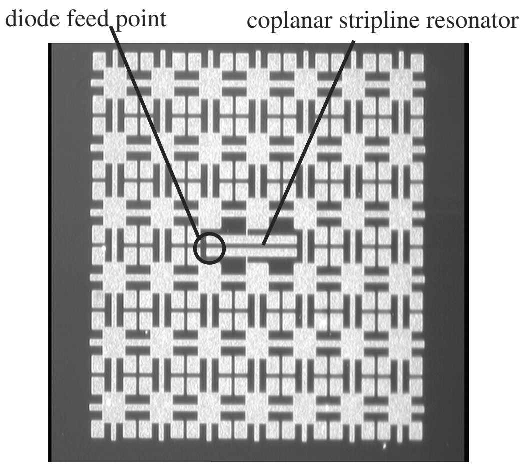


Figure 7: Wafer photograph of antenna. Aluminum metallization shown in bright grey.

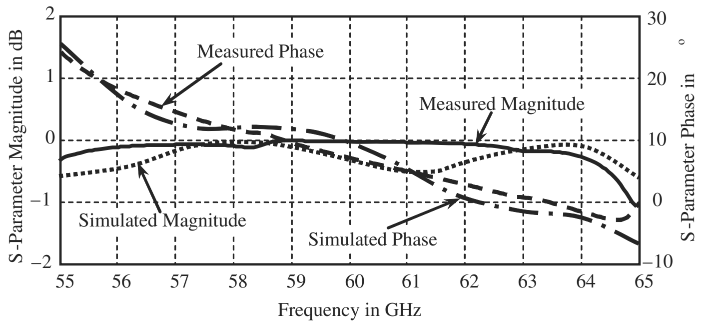


Figure 8: S-parameters of the UC-PBG antenna obtained using the Matrix Pencil Method

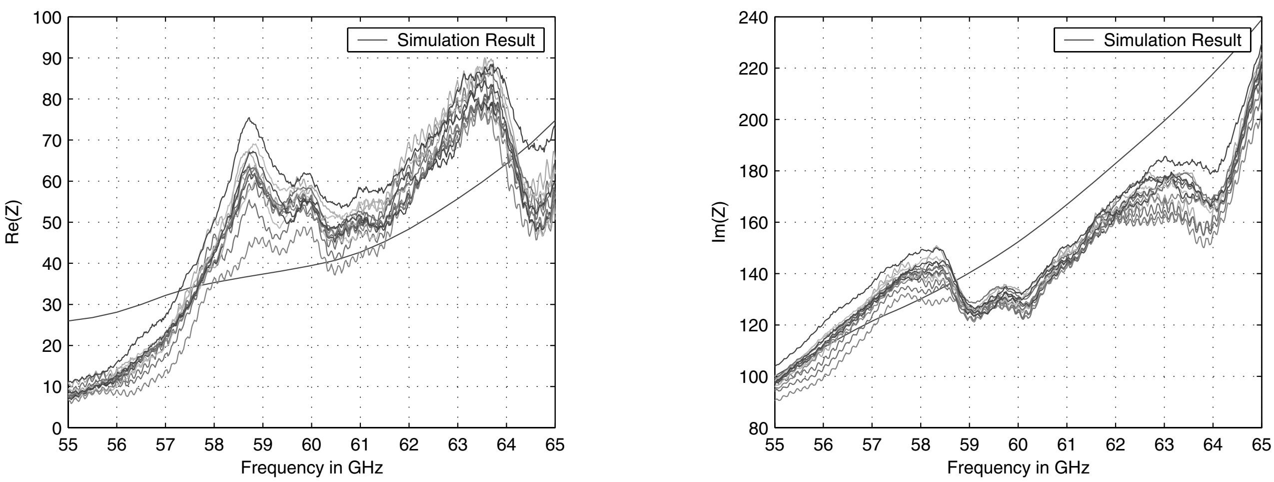


Figure 9: Measurement and simulation result of the impedance at the diode feed point, simulation result obtained using FEKO

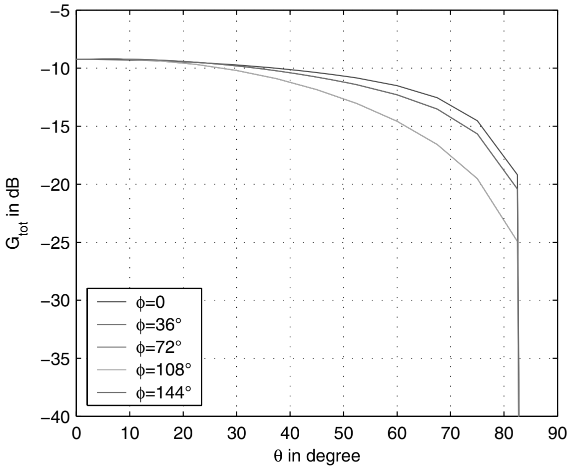


Figure 10: total gain of the UC-PBG antenna

Radiation Characteristics

The radiation characteristics of this UC-PBG antenna are shown in fig. 10. Here a maximum Gain of $G_{\text{max}} = -8\,\text{dB}$ is achieved, giving an increase of 40 dB over dipole structures. This corresponds to fig. 3, as the total power excited into the substrate modes is reduced.

Conclusion

An integrated active antenna design is proposed with significant improvement in antenna gain due to reduced substrate mode excitation. A system identification approach is used to speed up simulation performance. Measurement and simulation results show good agreement. A planar antenna structure was designed, modeled, fabricated and investigated experimentally. This structure has been designed to be used as an active millimeterwave antenna with an IMPATT diode as the active element. Using a coplanar resonator as the oscillator resonator and coupling element and a UC-PBG structure for conversion of the substrate modes excited via the resonator into the radiated wave excellent matching and a high radiation efficiency could be achieved. The complex electromagnetic full-wave simulation task could be performed in an efficient way by time-domain EM simulation in connection with system identification postprocessing.

Acknowledgements

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