Frequency Triplers at 94 GHz and 300 GHz for Millimeter-Wave Radars

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Abstract— In the framework of a ground-based cloud profiling radar at 94 GHz and a 3-D high-resolution imaging radar at 300 GHz developed at the Universidad Politécnica de Madrid, signal sources based on generation by direct digital synthesis, power amplification and frequency multiplication are designed. This work focuses on the last frequency multiplication stage of the source chain of both systems. The design of frequency triplers at 94 GHz and 300 GHz based on Schottky diode technology is reported. For the cloud profiling radar, the simulated room-temperature performance of the designed 94 GHz frequency tripler shows a conversion efficiency of around 11% in the 90-98 GHz frequency band for an input power of 100 mW, with a 3-dB bandwidth from 75 to 102 GHz. For the imaging radar, the simulated room-temperature performance of the designed 300 GHz frequency tripler predicts over 2% of conversion efficiency between 260 and 300 GHz for an input power of 100 mW.

I. INTRODUCTION

Two millimeter-wave radars have been recently developed at the Universidad Politécnica de Madrid for weather monitoring and security applications. On the one hand, a ground-based cloud profiling radar at 94 GHz [1] and, on the other hand, a 3-D high-resolution imaging radar at 300 GHz [2]. In both systems, the transmitted signal is generated by direct digital synthesis and several stages of frequency multiplication and power amplification. This work focuses on the design of two frequency triplers at 94 GHz and 300 GHz based on Schottky diodes for the last frequency multiplication stage of the transmitter chains of both radars.

The effects of current saturation and self-heating are the main performance limiting factors for millimeter-wave Schottky diode frequency multipliers. A physics-based electro-thermal model developed at the Universidad Politécnica de Madrid [3] which takes into account these effects is used in the design of the frequency triplers reported in this work. The design methodology details are presented in Section II, whereas the predicted performance of the designed frequency triplers at 94 GHz and 300 GHz are displayed in Section III and Section IV respectively.

II. DESIGN METHODOLOGY

The design methodology combines in-house simulation tools with conventional design software like Ansys HFSS and Keysight ADS. A physics-based numerical electro-thermal model for Schottky diodes coupled with a harmonic-balance code is used to optimize the diode electrical and geometrical parameters together with output power, conversion efficiency, and the impedances at the specific harmonics. This tool takes into account self-heating and the temperature dependency of the material parameters. In addition, it is able to calculate internal temperature distributions allowing the evaluation of the thermal effects on the circuit performance. Once the diode structure is selected, the synthesis of the circuit topology is performed with HFSS and ADS. The results obtained from the HFSS electromagnetic simulations of the actual 3-D circuit structure are included into ADS together with an appropriate diode model in order to determine the overall circuit performance. The design process is iterative (Fig. 1) and can be divided into three steps.

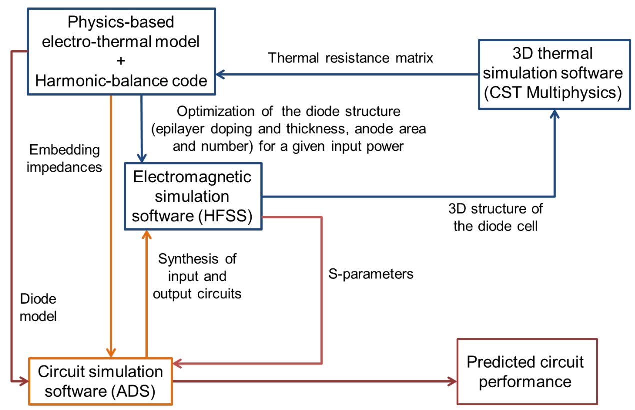

Fig. 1. Iterative design process utilized to optimize circuit performance.

A. Step 1

In the first step, the diode structure is optimized by using the physics-based numerical electro-thermal model integrated into a circuit simulator based on the harmonic balance technique. Parameters like epitaxial layer doping and thickness, and anode area and number are optimized for a given input power. Then, the diode cell is configured.

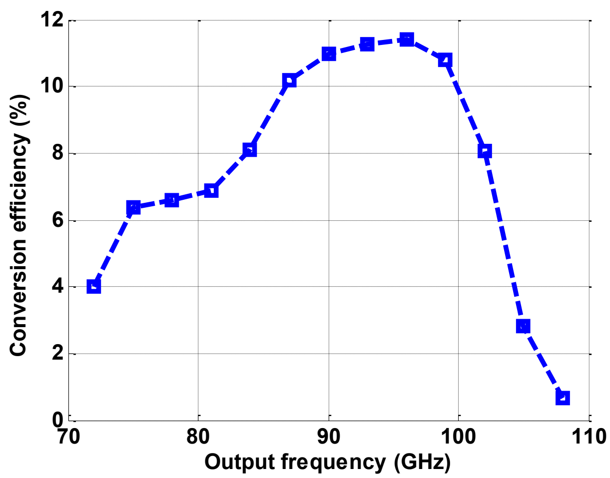

Fig. 2. 94 GHz frequency tripler: conversion efficiency as a function of output frequency for an input power of 100 mW.

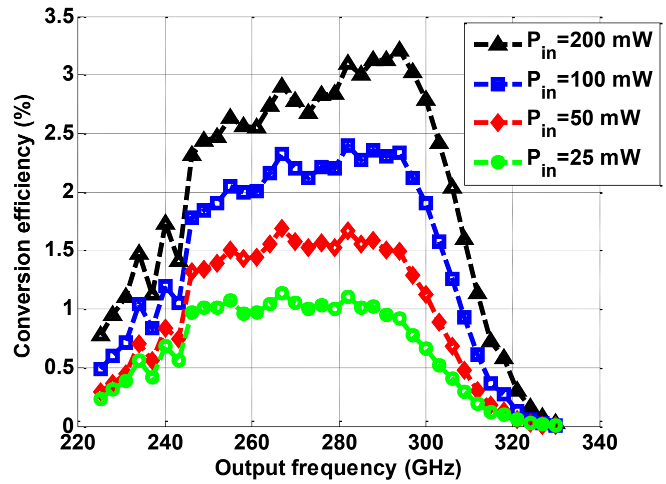

Fig. 3. 300 GHz frequency tripler: conversion efficiency as a function of output frequency for the 25-200 mW input power range.

A thermal resistance matrix [3] is extracted by simulating the 3-D structure of the diode cell with CST Multiphysics and applying the dissipated power obtained with the physics-based electro-thermal model.

Finally, the embedding impedances and diode model to be included into ADS are determined by using the physics-based numerical electro-thermal model in combination with the harmonic balance code. The diode parameters are reoptimized if necessary.

B. Step 2

In the second step, the matching networks of the input and output circuits are linearly simulated with ADS by using the embedding impedances extracted in Step 1 and the S-parameters of the diode cell.

C. Step 3

In the third step, the circuit performance is predicted by carrying out a nonlinear circuit simulation with ADS and using the diode model extracted in Step 1 and the S-parameters extracted from the HFSS simulations of the diode cell, and the input and output circuits.

III. 94 GHz Frequency Tripler

For the source of the cloud profiling radar, a frequency tripler providing around 4 mW of output power in the 93-95 GHz frequency band for an input power of 100 mW in the 31-31.66 GHz frequency band is required [1].

The predicted room-temperature performance of the designed 94 GHz frequency tripler shows a conversion efficiency of around 11% in the 90-98 GHz frequency band for an input power of 100 mW, with a 3-dB bandwidth from 75 to 102 GHz (Fig. 2), and a maximum anode temperature of around 400 K. This frequency tripler uses a discrete GaAs diode chip from Teratech Components Ltd. (UK) with six planar Schottky varactors in a series configuration.

IV. 300 GHz Frequency Tripler

The design of a 300 GHz frequency tripler for the 3-D high-resolution imaging radar is also presented. The design goal is to maximize the bandwidth for a wide range of input powers. This tripler features four anodes integrated into a GaAs membrane. Fig. 3 shows the predicted conversion efficiency for input powers between 25 and 200 mW. The 3-dB bandwidth is higher than 50 GHz for the whole simulated input power range.

V. Conclusions

The design of two frequency triplers at 94 GHz and 300 GHz by following a design methodology that includes an integrated thermal management approach has been presented. The predicted performance of both triplers fulfills the design requirements and will be compared against measurements once the circuits are fabricated.

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