PRELIMINARY DESIGN OF A 650 GHz SUBHARMONICALLY PUMPED MIXER WITH QUASI-VERTICAL SCHOTTKY DIODES

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Abstract

Preliminary design of a 650 GHz subharmonically pumped planar Schottky-diode mixer has been carried out. The mixer design is based on the use of scaled models. Before the implementation of the final mixer 2.5/5 GHz and 5/10 GHz scaled models as well as a 216 GHz mixer are designed and tested.

The mixer employs a modified split-waveguide mount design. The mount consists of RF and LO waveguides, an integrated diagonal horn, two sliding backshorts and shielded microstrip channels. The design is compact and fabrication of the mount is easy. Novel quasi-vertical planar Schottky-diodes will be used in the mixer.

The waveguide to shielded microstrip transitions and the filters have been designed and tested by using the 2.5/5 GHz scaled model. After that, a 10 GHz wideband subharmonic mixer has been constructed. Preliminary simulations and measurements predict a conversion loss of 6.7 dB and an IF bandwidth of more than 40 GHz at the scaled frequency of 650 GHz.

1. Introduction

Technology for the next century remote sensing applications is currently being developed by European Space Agency (ESA). In many space based receiver applications technology which does not require cryogenic cooling is preferred. Schottky-diode mixers have the property to work well at either cryogenic or room temperature. Thus, they are well suited in space based receivers. Whisker contacted diodes have shown the best conversion efficiency. Unfortunately, the receiver assembly and the space qualification process are complicated. The use of planar diodes allows easier space qualification with more convenient receiver design and assembly. The development for the replacement of whisker contacted Schottky honeycomb diodes by planar devices has been going on for a number of years.

We are in the process of designing 216 GHz and 650 GHz subharmonic waveguide mixers based on a quasi-vertical antiparallel diode pair configuration [1]. The subharmonic mixing is used because of the requirement for an LO frequency at only about one-half the RF frequency, simple RF diplexing, inherent LO noise suppression and broad achievable IF bandwidth. Consequently, a narrow band filtering for the LO noise suppression is not needed and several spectral lines can be measured with a single fixed-frequency LO (broadband IF matching possible). The quasi-vertical diode has properties similar to whisker contacted diode. This enables low conversion loss operation.

This paper contains the waveguide mount description, diode description, preliminary design and measurements with the 2.5/5 GHz and the 10 GHz scaled model. Also the modelling of the quasi-vertical planar Schottky-diodes through EM-simulations will be dealt with.

2. Waveguide Mount Description

The mixer employs a modified split-waveguide mount design [2], which has been successfully applied to a subharmonically pumped planar Schottky-diode mixer [3], and is also applicable for a doubler [4]. The primary modification compared to the original design is reduction of the number of sliding backshorts and the use of a bent LO waveguide. Figure 1 shows a schematic of the mixer mount. The RF signal is coupled into a 215 μm x 430 μm (dimensions are for the 650 GHz mixer, dimensions of the 216 GHz mixer are obtained by scaling) waveguide by a diagonal feedhorn and into the shielded microstrip channel by a waveguide to microstrip transition. The RF transition utilizes a microstrip line, which extends across and beyond the input RF waveguide allowing grounding. The LO signal is fed through the bent 425 μm x 850 μm waveguide, the waveguide to microstrip transition and a quartz microstrip LO filter to the antiparallel quasi-vertical Schottky-diode pair. The width and height of the shielded microstrip channel are 120 μm and 100 μm. The quartz substrate is 110 μm wide and 50 μm thick. The IF signal leaves the mixer through an IF filter followed by an SMA connector. The IF channel microstrip line is bonded to the main strip between the waveguides. Noncontacting backshorts will be used in the 216 GHz mixer, while the 650 GHz mixer employes contacting backshorts.

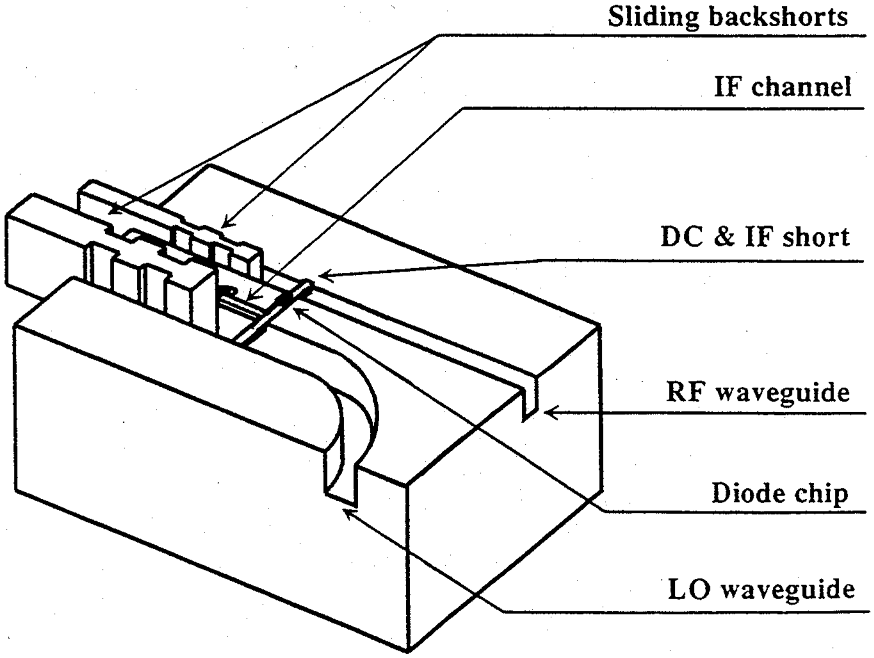


Figure 1. Schematic drawing showing one half of the subharmonic mixer mount (diagonal feedhorn not shown).

3. Mixer Diodes

The subharmonic mixers at 216 GHz and at 650 GHz will utilize a quasi-vertical planar Schottky-diode pair in an antiparallel configuration (APD). The diodes will be manufactured by Technische Hochschule Darmstadt (THD). The diode chip is shown in Figure 2. The chip will be attached onto the quartz substrate by using flip-chip technique as is presented in Figure 3. To reduce the effect of the parasitic impedances, GaAs substrate has to be removed in the 650 GHz mixer. The anode diameter is 0.8 µm on a 70 nm thick epilayer with doping concentration of $3 \cdot 10^{17}$ cm^{-3}. The diode series resistance is 16 Ω, ideality factor 1.1, saturation current lower than $1 \cdot 10^{-16}$ A and a zero bias junction capacitance 1.2 fF. The dimensions of the diode chip are 195 µm long and 110 µm wide. The thickness of the remaining semi-insulating GaAs substrate is reduced to 10-15 µm in order to lower the contribution to the parasitic capacitance. This diode chip will be used in both mixers (216 GHz and 650 GHz). If there is a need for further reduction of the parasitics, the GaAs substrate will be entirely removed after soldering the diode onto the microstrip (Figure 4).

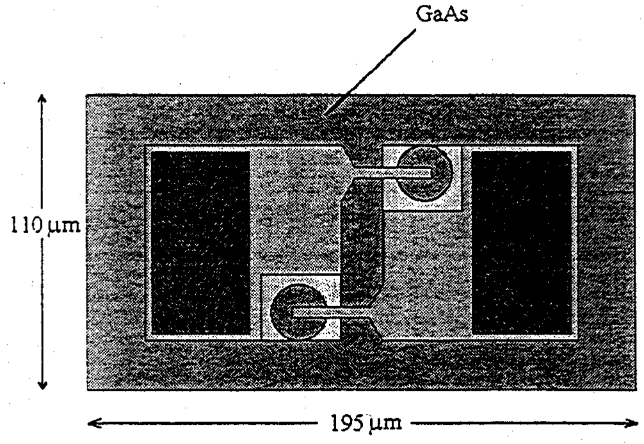


Figure 2. Antiparallel diode chip (APD).

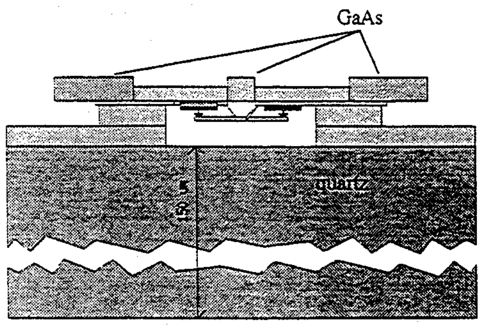


Figure 3. APD with GaAs on a 150 µm thick quartz substrate in the 216 mixer.

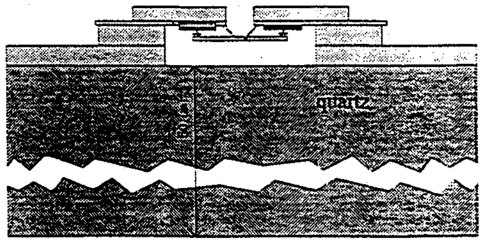


Figure 4. APD without GaAs on a 50 µm thick quartz substrate in the 650 GHz mixer.

4. Preliminary Design

The waveguide to microstrip transitions and the IF and LO filters were designed using the 2.5/5 GHz scaled model. EM-simulations were also carried out in order to verify de-embedding impedances at discrete frequencies and to find out accurate transmission line impedances in the shielded microstrip channel. Hewlett Packard's High Frequency Structure Simulator (HFSS) and an FDTD analysis in APLAC (a tool for circuit simulation developed by Helsinki University of Technology and Nokia Corporation) were used for EM-simulations.

The LO and RF transitions with measurement results are shown in Figures 5 and 6. For the LO transition, a 50 Ω transmission line was used. The width w_l of the 50 Ω line was determined by HFSS. The transition was optimized by changing the length l_w of the transmission line over the LO waveguide and the backshort position. The first step in optimizing the RF transition was to change the width l_l of the transmission line across the RF waveguide. Further optimimzation was done by changing the width l_2 of the transmission line beyond the RF waveguide. In this way, wideband transitions were obtained.

The sructure of the bandstop filter used for RF and LO rejection is shown in Figure 7. The lenghts and the number of the $\lambda_g/4$ stubs were optimized to obtain desired rejection at stopband. In Figure 8, the measured and simulated (FDTD) insertion loss of the LO filter are shown. With this filter structure, high rejection is easily obtained at a wide band.

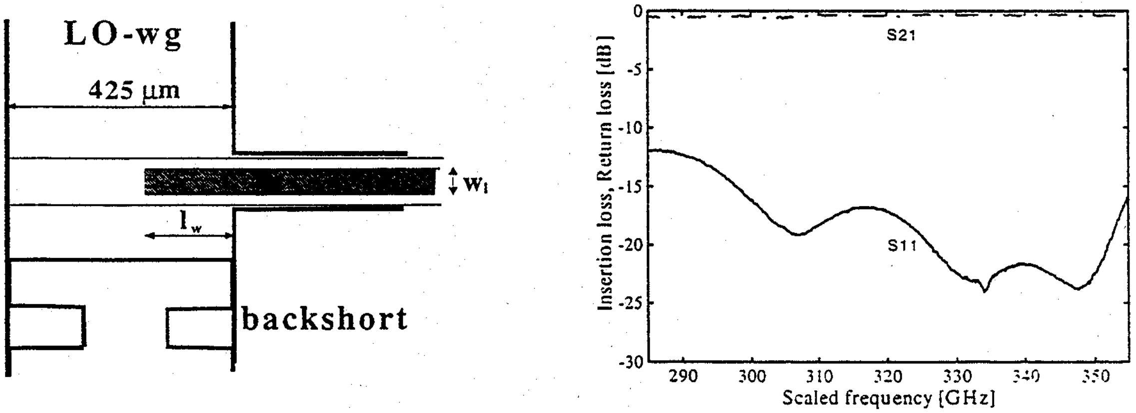


Figure 5. Structure and measured response of LO transition.

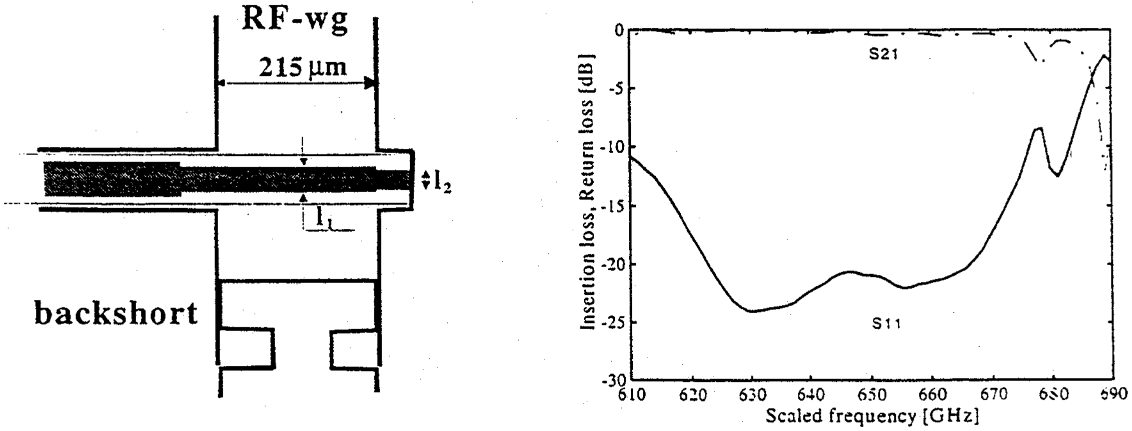
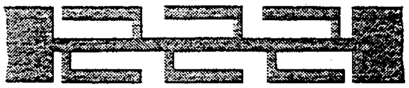


Figure 6. Structure and measured response of RF transition.



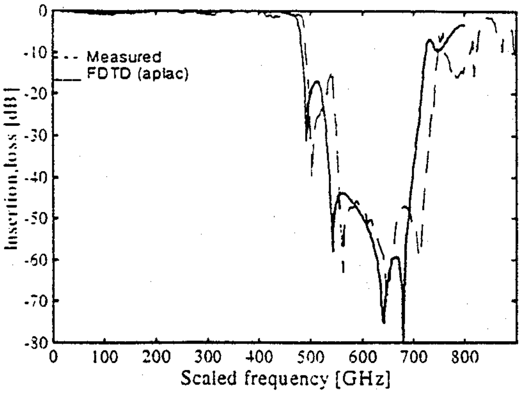


Figure 7. Structure of bandstop filter.

Figure 8. Measured and simulated insertion loss (dB) of LO filter.

A 10 GHz mixer has been designed and preliminary measurements have been done. GaAs beam-lead Schottky diodes have been implemented in the mixer. Diode parameters are given in Table 1 with corresponding impedance values. The diodes were chosen so that the impedance values of the parameters would match as well as possible to those of the 650 GHz mixer diode. The diodes were placed on the microstrip in antiparallel configuration. Harmonic balance analysis in Hewlett Packard's Microwave Design System (MDS) was used in order to find out the diode de-embedding impedances for minimum conversion loss. Simulation results are shown in Table 2. After determination of the de-embedding impedances, a mixer circuit was designed. The mixer circuit is presented in Figure 9. Two bonding wires were used in order to connect the IF channel to the coaxial connector and to the main strip. The diodes were placed near the RF transition in order to minimize signal losses. The measurement results are shown in Figures 10 and 11. In Figure 10, the conversion loss is presented versus the scaled IF frequency. According to the preliminary measurements a scaled IF bandwidth of more than 40 GHz is achievable. The conversion loss versus the LO power requirement is presented in Figure 11. In the simulation of the 10 GHz mixer the LO power was 10 dBm. Measured LO and RF return losses were over 11 dB and over 13 dB at 10 dBm LO power.

Table 1. Parameters of the beam-lead diode.

Series resistance	R_s	10 Ω
Zero junction capacitance	C_{jo}	0.13 pF (122 Ω)
Parasitic capacitance (package)	C_b	0.14 pF (114 Ω)
Parasitic inductance (package)	L_b	0.6 nH (38Ω)
Ideality factor	η	1.18
Saturation current	I_s	$4.46 \cdot 10^{-13}$ A

Table 2. Simulation results of the 10 GHz APD mixer.

RF impedance	Z_{RF}	(10+j5) Ω
LO impedance	Z_{LO}	(14-j20) Ω
IF impedance	Z_{IF}	50 Ω
Conversion loss		6.7 dB
Noise temperature		500 K
P_{LO} requirement		10 dBm

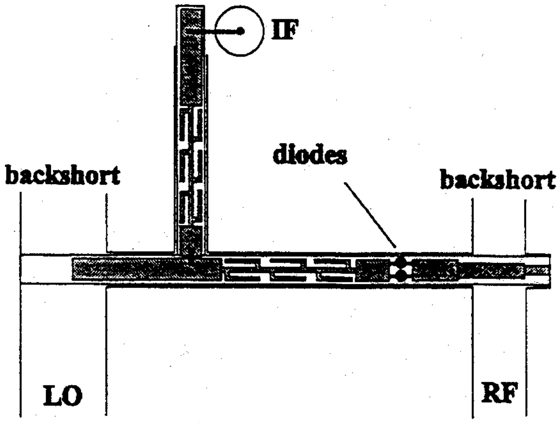


Figure 9. 10 GHz mixer circuit.

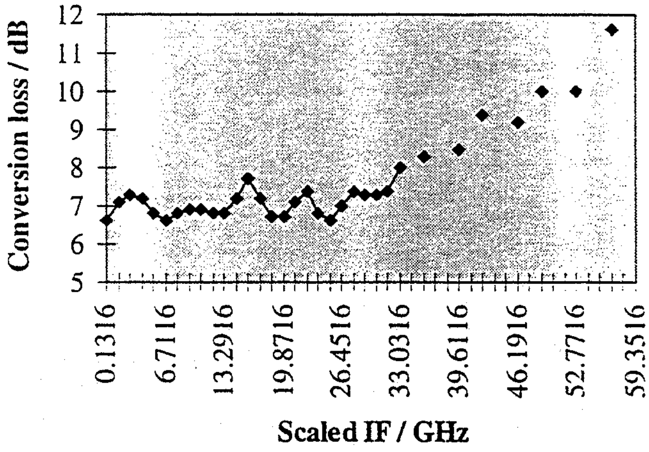


Figure 10. Conversion loss vs scaled IF frequency.

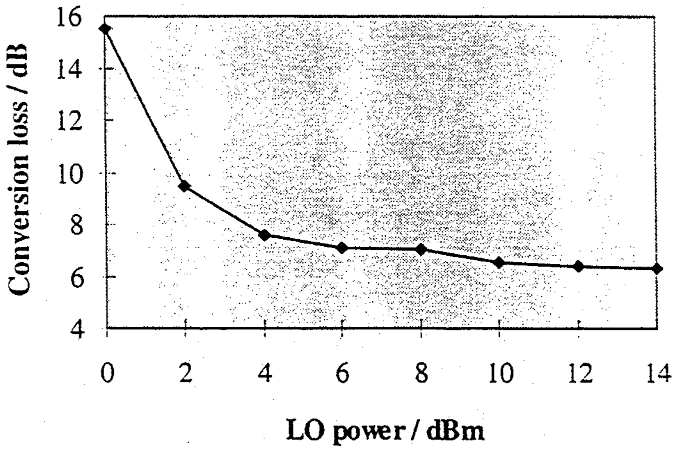


Figure 11. Conversion loss vs LO power.

5. Diode Modelling

In order to obtain a good mixing performance an accurate diode model is required. The equivalent circuit of the Schottky junction has been extensively investigated in [5]. At high frequencies, the parasitic impedances created by the diode chip structure have a significant effect on the mixer performance. We are studying the diode modelling by EM-simulations (HFSS) and broadband measurements. Both diodes, the 216 GHz diode with excess GaAs on the backside of the diode chip and the 650 GHz diode without GaAs, will be modelled. The effects of the associated substrate and the microstrip channel are taken into account by placing the diode chip into the shielded microstrip channel.

The HFSS simulations are made in three main phases. First, only the diode pads and the cathode metallization are simulated. After that, the anode finger is included with the junction short-circuited. Finally, the total capacitance of the junction and the fringing fields are obtained by simulating the diode with the epitaxial layer depleted. In each phase, two-port S-parameters produced by HFSS are compared with the equivalent circuit model so that the entire equivalent circuit is obtained step by step. The optimization routines in MDS are used in order to match the S-parameters with the equivalent circuit and to obtain the circuit element values.

The diode model is shown Figure 12. The subcircuits contain the equivalent circuits for the diode pads. The physical transmission line is used to model the cathode metallization. In the first phase of the simulation, the gap between the anode pad and the cathode metallization is modelled with the parasitic capacitances (C_{g1}, C_{ac} and C_{g2}). The anode finger inductance (L_f) is obtained in the second phase. The fringing field capacitance (C_{fr}) is extracted from the total capacitance obtained in the last phase of the HFSS simulations. After the simulation of the parasitic impedances, the junction model (R_j, C_j, R_s and L_s) is added into the diode equivalent circuit. At the moment simulations are in progress. Measurements will be started during spring -97.

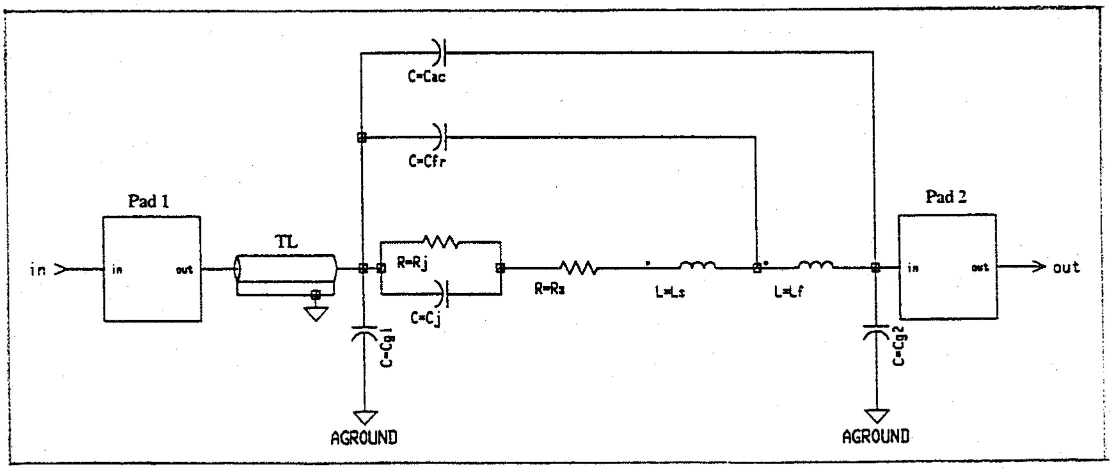


Figure 12. Diode equivalent circuit (the equivalent circuits of the diode pads not shown).

6. Conclusion

Preliminary design of a subharmonic mixer at millimeter and submillimeter frequencies has been carried out by simulations and scaled model measurements. According to the scaled model measurements, a broadband low-conversion-loss subharmonic mixer at 650 GHz can be achieved. This compact mixer structure can be scaled even for higher frequencies. The use of quasi-vertical diodes with properties almost similar to whisker contacted diodes makes low-conversion-loss mixing possible.

References

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