A 320GHz Low Drive Level Sub-harmonic Mixer Based on Quantum Barrier Junctions

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***Abstract*—A sub-harmonically pumped (n=4) down conversion mixer, employing single quantum barrier junction in place of a Schottky pair, is designed and simulated using the symbolically defined device capability in ADS and transmission line optimisation using HFSS prior to fabrication. The performance in terms of conversion loss and LO power requirements are estimated and compared with state-of-the-art Schottky diode mixers. The intent was to explore a low drive level mixer with high conversion efficiency (minimum conversion loss) for potential use at sub-millimetre wave frequencies, where the device parasitic's, such as junction capacitance and series resistance have a marked effect on performance and where LO pump powers are often weak. The performance is explored via a design operating at 320GHz and showing a signal side band (SSB) conversion loss with 5.7dB, with only -9.5dBm (≈0.1mW) of LO power. The conversion loss is maintained below 10dB, even when using -8dBm to -11dBm of LO drive level, and the eventual aim of the work is to realize a similar design with an operating frequency of 640GHz for meteorological studies.**

I. Introduction

ALTHOUGH appreciable advances have already been achieved within the sub-millimeter wave region (namely what's commonly referred to as the lower end of the THz gap), covering a wide range of potential applications, this interesting frequency region still merits more systems development in terms of detecting signals at low LO pump powers. Especially low LO powers, in the presence of typically weak signals, such that the high power end of the dynamic range is not an issue, favor multi-element detection for faster scanning in either imaging or beam-steering applications. In the literature, the most common mixing devices used for heterodyne receiver/transmitter purposes are hot-electron bolometers (HEB), superconductor- insulator-superconductor (SIS) and Schottky diodes. SIS [1] and HEB [2] based mixers show excellent sensitivity and dominate ground based radio astronomy applications, but their super-cooled nature make them expensive, power hungry and difficult to use. Schottky diode based mixers are the work-horse of super-heterodyne detection even though they typically have less sensitivity and a very significantly larger LO power requirement.

A prerequisite for efficient sub-harmonic mixing is a non-linear element with an anti-symmetric I-V characteristic. Currently, this is achieved via the use of a back-to-back pair of Schottky diodes. However, a certain type of quantum barrier device (QBDs), known as a resonant tunneling diode (RTD) has a single junction capable of producing the same anti-symmetric I-V curve and who's performance in the context of a sub-harmonic mixer (n=4) is investigated in this work. A sub-harmonic number of four (n=4) was chosen to favor pumping by a much lower LO frequency where ample power is readily available. The ultimate goal of the work is to realize a mixer which is capable of detecting signals in the 580-750GHz atmospheric window, whilst using a 150-190GHz LO, and where x's 3 multipliers are able to supply 10's of mW's of pump power, and the investigation here is to study the design of a 320GHz scaled version in the first instance.

II. Design Methodelgy

Firstly the thermally assisted tunneling I-V characteristic of RTD was estimated using the Symbolically-Defined Device (SDD) capability provided in Keysight Technologies ADS since no "built-in" RTD models are currently available in this format. Secondly the subharmonic mixer circuit was divided into two matching networks, named the RF/IF and the LO, which were optimized in Ansys HFSS individually as shown in Fig.1.

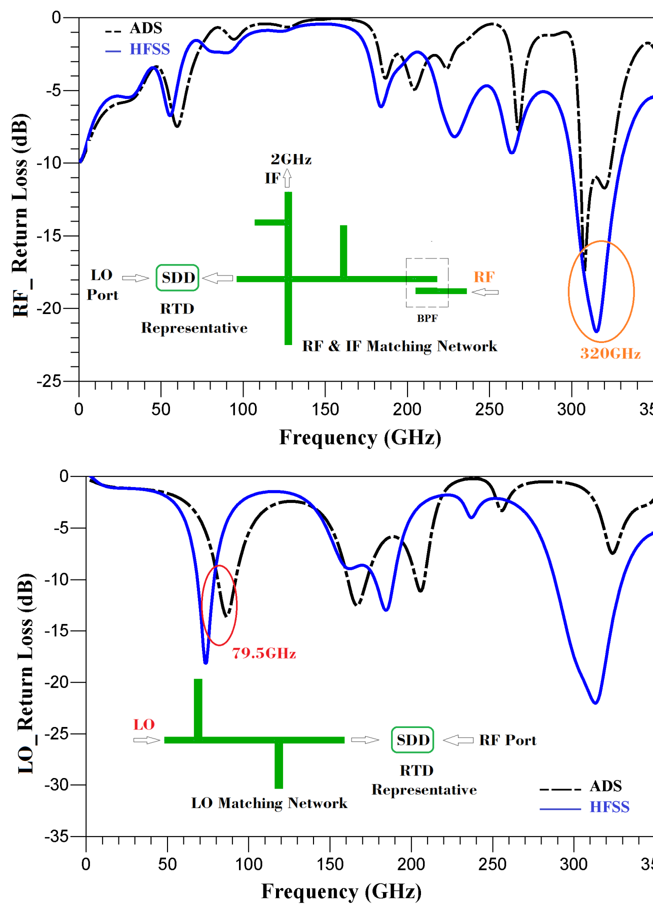

Fig.1. Input matching networks, RF and LO.

Beside these matching networks, two different waveguide to microstrip transitions using antipodal finline tapers are validated using HFSS in order for the RF and LO signals to be transformed from the waveguide mode to the microstrip mode. The HFSS results of these elements were again exported to ADS in the form of S-parameters blocks, shown in Fig.2, to precisely estimate the whole performance of the mixer comprised the discontinuity effects.

III. Results

A 320 GHz sub-harmonic mixer employing a pair of RTD's (in place of 4 Schottky diodes) and pumped with a 79.5 GHz LO signal is depicted in Fig.2. The simulated performance based on a Microstrip realisation, including RWG to microstrip transition losses, is presented in Fig.3 which shows a SSB conversion loss better than 6dB at an LO pump power of < -9dBm. Furthermore this design demonstrates better than 30dB port to port isolation.

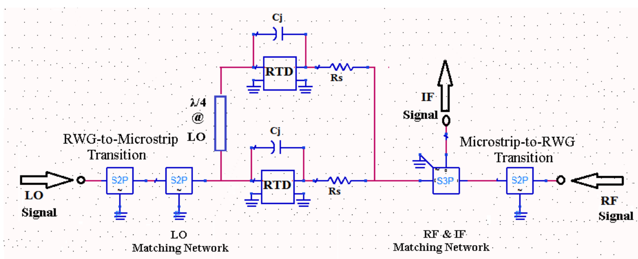

Fig.2. A configuration of 320GHz sub-harmonic mixer.

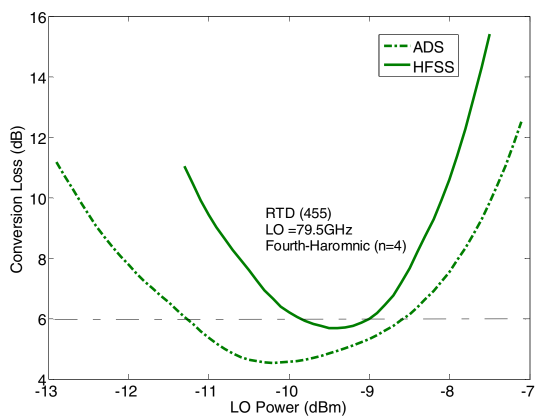

Fig.3. Conversion loss as a function of LO power.

Table 1 compares the RTD result presented in the current work to other published outcomes, based back to back Schottky diodes. The RTD performance in terms of the conversion loss is clearly impressive especially at sub-millimeter wavelengths and at this low harmonic number and with this LO power requirement, which are extremely low when compared with the Schottky diodes. According to the RTD's growth structure [8] (i.e., single quantum well sandwiched between two adaptable barriers), such a low drive level is expected since the RTD knee (i.e., the initial point of the non-linear region) of the I-V curve starts off at 0.15V which is around a quarter of that for a GaAs Schottky voltage (typically 0.7V), thus using single RTD junctions in place of a Schottky diode pair can be considered as a very promising alternative.

Table 1: Results Comparison.

Freq. (GHz)	CL (dB) *simulated	Device	LO Signal (GHz)	LO Power (dBm)	Bias	Ref.
182	12.7	Schottky	91	+6.5	±0.4V	[3]
170 - 210	16-12	Schottky	80	+10	1.1mA	[4]
215 - 225	8.2*	Schottky	105	__	none	[5]
310-350	5.7* DSB	Schottky	155	+7	none	[6]
340	10.1 SSB 7.3*	Schottky	170	+6	none	[7]
320	**< 6* SSB**	**RTD**	**79.5**	**-9.5**	**none**	**This work**

IV. Conclusion

The prospect of using RTDs to detect a sub-millimetre wave signals using extremely low LO powers was investigated in this work, and steps to fabricate and measure these circuits is presently underway.

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