ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 6, Issue 10, October 2017

# An Investigation of Resonant Tunnelling Diodes for sub-millimeter mixing applications

**M. Elsaadi, A. Riheel, S. Mohammed, S. Eqab**

***Abstract*—This paper investigates the potential performance of resonant tunneling diodes (RTDs), as nonlinear devices in place of Schottky diodes, in a fourth sub-harmonic down conversion mixer for prospective use at sub-millimeter frequency region. KeysightADS and AnsysHFSS are employedto design the intended mixer circuit. The Symbolically Defined Device (SDD) capability in ADS is used to model the RTDs,while HFSS is used to optimize the impedance matching networks based microstrip transmission lines. The performance is explored through a design operating at 340GHz. The simulated results show a signal side band (SSB) conversion loss < 5dB at Local Oscillator (LO) power of -10dBm. The conversion loss is maintained below 10dB, even when using -7dBm to -13dBm of LO drive level. This performance is compared with state-of-the-art Schottky diode mixers, where the aim is to explore a low pumped mixer with promising minimum conversion loss.**

***Index Terms*— Resonant tunnelling diodes, Passive mixer, Down-conversion, Conversion loss.**

## I. INTRODUCTION

The core element of a mixer is a non-linear junction, where its nonlinearity is responsible for providing the mixing between two input frequencies and producing a set of new output frequencies, whether down-conversion or up-conversion, by respectively taking the difference or the sum of these two main input frequencies and their harmonics. Depending on the preferred application, the mixers can be one of three main types, single ended, single balanced, or double balanced. The performance of mixers is generally evaluated through their Conversion Loss (CL), Noise Figure (NF), Local Oscillator (LO) drive, and isolation between the ports. Among these, the primary figures of merit are the CL and the LO pump power. The CL is defined in dB to provide the difference in power level between the desired output signal and the input signal, while the LO power represents the required level at which the optimum performance of a mixer can be demonstrated.

Fundamental and sub-harmonic mixers are the broadest classifications where millimetre and sub-millimetre wave mixing devices can be operated. In principle, the operatingmode depends on the selected harmonic number of the LO signal (usually 2$^{nd}$ or 4$^{th}$ harmonic) for satisfying a certain application requirement. At millimetre and sub-millimetre wave frequencies the device parasitic, such as junction capacitance and series resistance, have a marked effect on performance, and LO pump powers are often weak. Fundamental mode means that the intermediate frequency (IF) is only obtained by mixing the fundamental frequency of a radio frequency (RF) signal with that of the LO signal, while the IF signal in sub-harmonic-type operation is produced by taking the difference between the fundamental frequency of a RF signal and where the LO is a sub-harmonic of this, typical a half or quarter of the RF signal.

At the lower end of the THz gap, known as the sub-millimeter wave region, systems/sub-systems development is extremely required, even if significant advances being achieved within this interesting frequency region. Particularly detecting weak signals using low amount of Local Oscillator (LO) pump powers, in turn, the dynamic range (high power end) is not a problem, favor applications based on faster multi-element detection. According to the Literature, superconductor-insulator-superconductor (SIS), hot-electron bolometers (HEB), and Schottky diodes are the most employed mixing elements for receiving/transmitting purposes. For remote sensing applications, HEB[1] and SIS[2], as mixing devices, have presented a superb sensitivity and engaged a significant place, yet these devices naturally need to be super-cooled leading to restrict their use in some applications. Mixers based on Schottky diode are occupied a considerable place in heterodyne detection, although they show less sensitivity and require expensive amount of LO powers.

In principle, for a sub-harmonic mixer to be functioned efficiently, a nonlinear device producing an anti-symmetric current-voltage curve is inevitably required. At present, anti-parallel diode pair of Schottky diodes is used to meet this prerequisite. However, a single junction device known as a resonant tunnelling diode (RTD), which is a promising type of quantum barrier devices, produces an anti-symmetric I-V characteristic similar to that of the Schottky diodes pair. The performance of this RTD, as a mixing element, in a sub-harmonic mixer is explored in the current paper where the investigation is to study the potential design of a 340GHz in the first instance, using the fourth harmonic of a LO signal (84.5GHz) for pumping by a very low LO power.

***Manuscript received Oct,2017***

***M.Elsaadi**, Electronic and Electrical Department, Faculty of Engineering/University of Tobruk, (e-mail: elsaadi.mussa@gamil.com). Tobruk, Libya, Mobile No +218923478845.*

***A.Riheel**, Electronic and Electrical Department, Faculty of Engineering/University of Tobruk, (e-mail: AlmahdiRiheel@gmail.com). Tobruk, Libya, Mobile No +218944407908.*

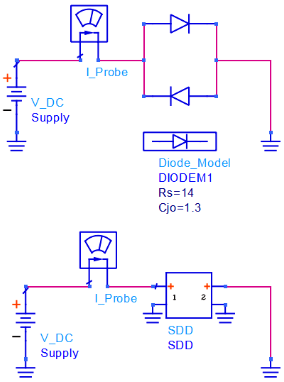
***S.Mohammed**, Electronic and Electrical Department, Faculty of Engineering/University of Tobruk, (e-mail:eng.seham22@gmail.com). Tobruk, Libya.*

***S.Eqab**, Electronic and Electrical Department, Faculty of Engineering/University of Tobruk, (e-mail: s.eqab.libya@gmail.com). Tobruk, Libya.*

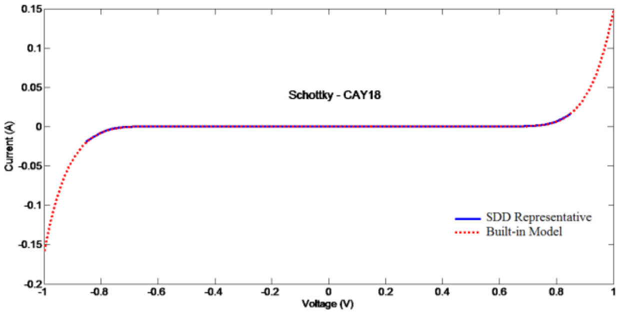
The RTD used in the current work was fabricated and aimed at oscillator use [3]. It is employed here in a simulation environment to explore its potential use in mixing applications by scaling its growth structure. In other words, the selected series resistance (Rs) and junction capacitance (Cj) are 14Ω and 1.3fF respectively, which are similar to the typical values for Schottky diodes at this frequency range [4]. Although the Schottky junction structure is different to that of the RTDs, the aim is to evaluate the RTDs in terms of nonlinearity and power requirement when compared to equivalent Schottkies.

## II. METHODOLOGY

In order to model RTDs in a CAD environment and to make a comprehensive comparison with the counterpart Schottky diode pair, the Symbolically Defined Device (SDD) model provided in the ADS environment is used as no built-in RTD models are available. The SDD model only represents the nonlinear resistor (i.e., the thermally assisted tunnelling I-V characteristic) without the associated elements such as series resistor and parallel capacitor. For verifying the reliability of the SDD model, two different approaches were compared. The built-in Schottky model and the author's own SSD model description of a commercial Schottky were used to prove the validity of the SDD model in comparing the Schottky's performance in terms of conversion loss.



a).The built-in Vs. the SDD model of the Schottky diode.



b).The measured and fitted current-voltage characteristic of a commercial Schottky diode

Figure 1. A commercial Schottky diode: a) The built-in and the SDD configuration and, b). The measured and fitted I-V curve.

The comparison between the built-in diode model and the Schottky representation showed a good agreement as shown in Fig.1. Therefore the SSD modelling approach can be considered as a trustworthy tool to estimate the likely performance of the RTD.

The design methodology stages are illustrated in Fig.2. The I-V characteristic of the RTD is firstly modelled using the SDD capability, based on fitting a polynomial to the measured RTD I-V curve using Matlab software. Secondly the sub-harmonic mixer circuit is divided into two impedance matching networks, named the RF/IF and the LO, which are individually optimized in Keysight ADS and Ansys HFSS. Beside these matching networks, a short circuit stub at RF frequency to LO side is added to present a reflection path of RF signal to be applied again to the RTD, and this will not affect the LO signal. Likewise, an open stub at LO frequency to RF side works as a short circuit of LO while provides an open circuit of RF signal. In the same way, the IF output signal can be extracted by adding series and shunt stubs at the IF side with λ/4 (λ is the wavelength) at RF frequency. The HFSS results are exported back to ADS in the form of S-parameters blocks and included in the ADS model to accurately estimate the whole performance of the mixer, including the discontinuity effects (i.e., the Tees and Crosses of microstrip transmission lines).

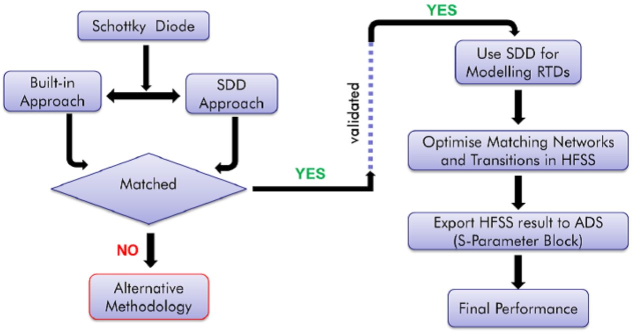


Figure 2. The design methodology flow chart.

## III. RESULTS AND DISCUSSION

A topology of a sub-harmonic down conversion mixer exploiting the fourth harmonic of the LO signal is shown in Fig.3. This sub-harmonic mixer is intended to down convert a high frequency signal (RF) of 340GHz to an intermediate frequency signal (IF) in the range of 2GHz by mixing the fourth harmonic of an 84.5GHz LO signal. The non-linear elements used are a two single junction RTDs (instead of two-pairs of Schottky diodes), separated by a quarter wave transmission line at the LO frequency.

The design is based on Microstrip transmission lines, which have a width of 35μm and a metal thickness of 1μm, while the height of the quartz substrate is 100μm.The final physical mask of this 340GHz mixer is shown in Fig 4, and it is already prepared for subsequent fabrication. The simulated performance is presented in Fig.5 which shows a SSB conversion loss better than 5dB at a LO pump power of < -10dBm. Furthermore this design exhibits an excellent port to port isolation, better than 35dB as shown in Fig.6.

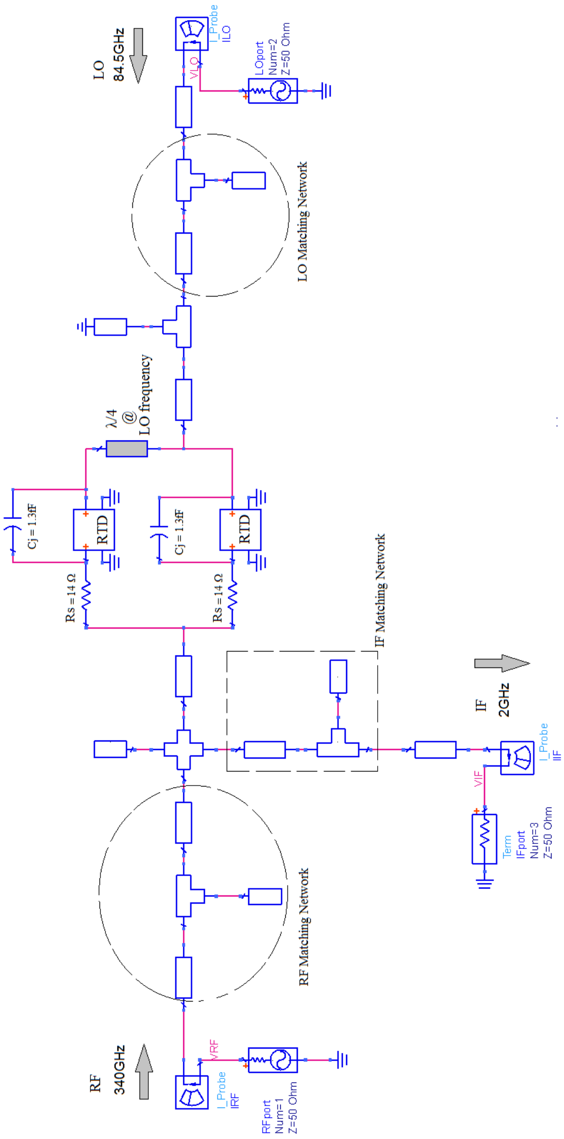


Figure 3. A 340GHz sub-harmonic mixer topology.

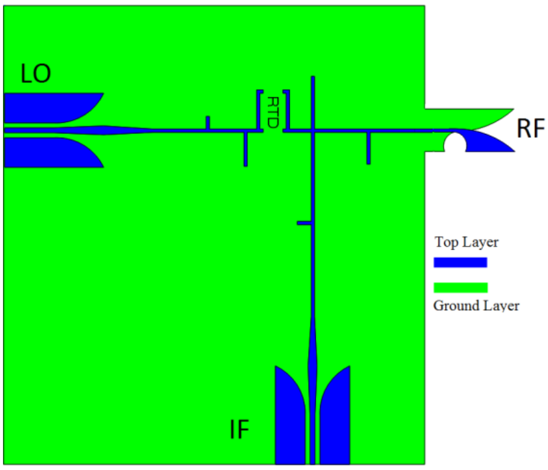


Figure 4. 340GHz mixer’s physical mask based on 100µm quartz.

These results are without considering discontinuities effects in ADS, while the conversion loss is increased by around 2dB when these discontinuities are taken into account by HFSS.

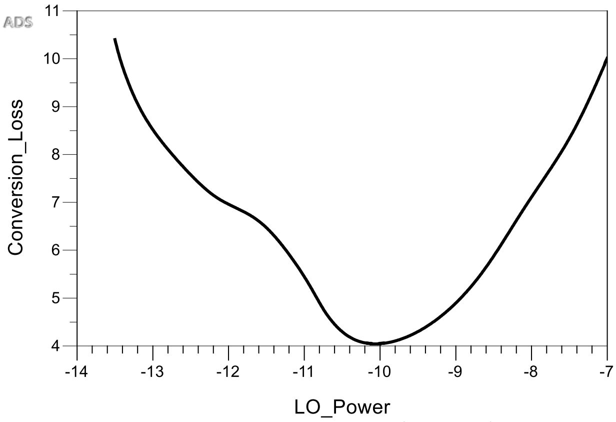
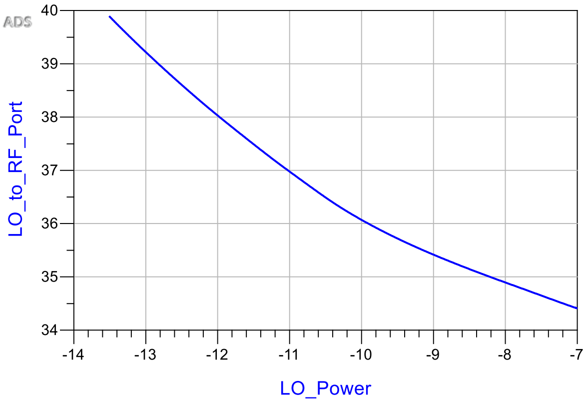
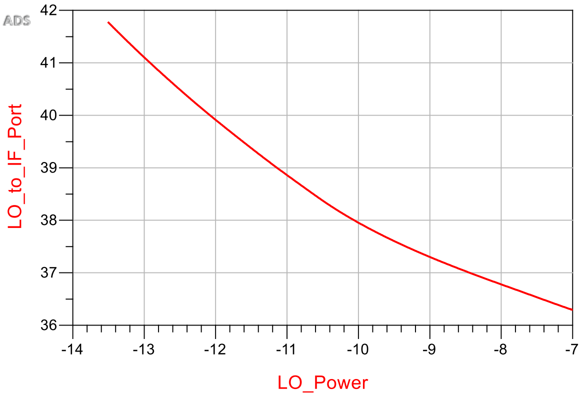


Figure 5. Conversion loss (dB) as a function of LO power (dBm).



a).LO to RF port isolation.



b).LO to IF port isolation.

Figure 6.Port isolation, a) LO to RF port and, b) LO to IF port.

Table 1 below compares the current mixer based RTD to anti-parallel diode pair of Schottky diodes, published in the literature. As seen from the table, the RTD performance in terms of the LO power requirements is very low when compared to Schottky diodes, favored and valued at this sub-THz region. Furthermore the mixer shows a promising conversion loss. This extremely low drive level is expected as the non-linear region starts at around 0.2V, while for Schottkies is around 0.7V. In principle, the RTD growth structure consists of single quantum well surrounded by double adapted barriers. Consequently a single RTD junction can be usedinstead of a Schottky diode pair.

| Freq. (GHz) | CL (dB) simulated | Device | LO Signal (GHz) | LO Power (dBm) | Bias | Ref. |
|---|---|---|---|---|---|---|
| 210 | 6.5 SSB | Schottky | 108 | 3.8 | none | [5] |
| 310-350 | 5.7 DSB | Schottky | 155 | +7 | none | [6] |
| 340 | 7.3 SSB | Schottky | 170 | +6 | none | [7] |
| 422 | 7.4 SSB | Schottky | 210 | +5.3 | none | [8] |
| 340 | 8.5 DSB | Schottky | 170 | +7 | none | [9] |
| **340** | **<5 SSB** | **RTD** | **84.5** | **-10** | **none** | **This Paper** |

Table 1: Results Comparison with publishedresults of Schottky diodes.

## IV. CONCLUSION

The potential use of RTDs, as sub-millimeter mixing element using very low amount of LO plumed power, was explored in this paper. The performance wasa promising compared to the counterpart Schottky diodes. The next step is to fabricate a scaled version to confirm the methodology and validate thecurrent simulated results.

## ACKNOWLEDGMENT

Authors thank Dr. DP Steenson for providing the RTD measured data used in the current work.

## REFERENCES

[1] A. D. Semenov *et al.*, "Superconducting hot-electron bolometer mixer for terahertz heterodyne receivers," *IEEE transactions on applied superconductivity,* vol. 13, no. 2, pp. 168-171, 2003.

[2] J. W. Kooi*et al.*, "A 275–425-GHz tunerless waveguide receiver based on AlN-barrier SIS technology," *IEEE Transactions on Microwave Theory and Techniques,* vol. 55, no. 10, pp. 2086-2096, 2007.

[3] G. Millington, R. E. Miles, R. D. Pollard, D. P. Steenson, and J. M. Chamberlain, "A resonant tunnelling diode self-oscillating mixer with conversion gain," *IEEE microwave and guided wave letters,* vol. 1, no. 11, pp. 320-321, 1991.

[4] R. S. Michaelsen, T. K. Johansen, and V. Krozer, "Design of a× 4 subharmonic sub-millimeter wave diode mixer, based on an analytic expression for small-signal conversion admittance parameters," in *Microwave & Optoelectronics Conference (IMOC), 2013 SBMO/IEEE MTT-S International*, 2013, pp. 1-4: IEEE.

[5] Y. Zhang, W. Zhao, Y. Wang, T. Ren, and Y. Chen, "A 220 GHz subharmonic mixer based on schottky diodes with an accurate terahertz diode model," *Microwave and Optical Technology Letters,* vol. 58, no. 10, pp. 2311-2316, 2016.

[6] B. Zhang *et al.*, "The design of a 310–350-GHz sub-harmonic mixer with planar schottky diodes," in *Signals Systems and Electronics (ISSSE), 2010 International Symposium on*, 2010, vol. 2, pp. 1-3: IEEE.

[7] L. Miao, J. Jiang, C. Wang, X.-J. Deng, and B. Lu, "A 340GHz sub-harmonic mixer based on planar Schottky diodes," in *Infrared, Millimeter, and Terahertz waves (IRMMW-THz), 2014 39th International Conference on*, 2014, pp. 1-2: IEEE.

[8] G. Liu, B. Zhang, L. Zhang, D. Xing, J. Wang, and Y. Fan, "420 GHz subharmonic mixer based on heterogeneous integrated Schottky diode," *IEICE Electronics Express,* vol. 14, no. 12, pp. 20170459-20170459, 2017.

[9] J. Wang *et al.*, "An integrated membrane sub-harmonic Schottky diode mixers at 340GHz," in *Selected Proceedings of the Photoelectronic Technology Committee Conferences held June-July 2015*, 2015, pp. 97950R-97950R-6: International Society for Optics and Photonics.

**M.Elsaadi** has been awarded a PhD from University of Leeds (United Kingdom) in Electronic and Electrical Engineering, August 2016. Fully skilled in designing RF transmitters and receivers for up and down-conversion mixing applications, covering the operating frequency from RF-to-Sub-millimeter waves band. His area of interest are Microwave Devices and MEMS Sensors and actuators.He is a member of IEEE and IET.

**A.Riheel**, will be awarded a BSc (November, 2017)in Electronic and Electrical Engineering, University of Tobruk, Libya. His area of interest is RF Front end components, and Radars as transmitters and receivers.

**S.Mohammed**, will be awarded a BSc (November, 2017)in Electronic and Electrical Engineering, University of Tobruk, Libya. Her area of interest is RF Front end components, and Radars as transmitters and receivers.

**S.Eqab**, will be awarded a BSc (November, 2017)in Electronic and Electrical Engineering, University of Tobruk, Libya. Her area of interest is RF Front end components, and Radars as transmitters and receivers.