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Investigation of mm-wave RTD Based Amplifiers

V. Doychinov*, D.P. Steenson*, S. Muttlak†, J. Sexton†, and M. Missous†
*Institute of Microwaves and Photonics, University of Leeds, UK
†School of Electrical and Electronic Engineering, The University of Manchester, UK

***Abstract*—This work explores the applicability of Resonant Tunnelling Diodes as active elements in two different amplifier configurations in the range 25 GHz – 35 GHz, with a view of implementing scaled versions at W-band and beyond, as front-end narrow-band low-noise amplifiers. On-wafer S-parameter measurements are used to represent devices in simulation software for increased fidelity. Initial results are promising, showing close to 10 dB gain at 30 GHz.**

I. INTRODUCTION

THE use of Resonant Tunnelling Diodes (RTDs) as oscillator elements in the THz region has been previously demonstrated [1]. Their application as building blocks in mixer and amplifier circuits with low power requirements has also been investigated [2]–[4]. This work reports on RTD amplifier circuit designs at the lower end of the millimetre-wave region with a strong potential of scaling these to operate at W-band and higher frequencies.

Two different amplifier circuit topologies were used to evaluate the RTDs' performance, a reflection-based one, and a distributed transmission line. Devices with varying active area were simulated, with typical best results given here. It was found that for both approaches, the gain-bandwidth product, as well as centre frequency, can easily be adjusted via tuning stubs.

II. DEVICES USED

The RTDs used were grown on an InP substrate with AlAs barriers and InGaAs well, exhibiting $J_p = 25kA/cm^2$ and high PVCR (5.9) [5]. An example measured DC I-V characteristic for positive applied voltage is shown in Fig. 1. Additionally, on-wafer S-parameters measurements between 30 MHz and 40 GHz were taken at different bias voltages, including within the Negative Differential Resistance (NDR) regions. Both devices with a $4\mu m^2$ and $9\mu m^2$ active area were evaluated, with results reported in Section IV obtained using the former.

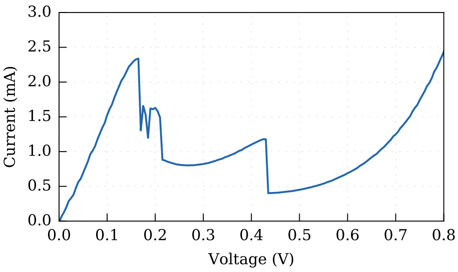


Fig. 1. Measured DC I-V of an RTD with a $9\mu m^2$ mesa area.

III. AMPLIFIER CIRCUITS

The main principle behind the 2-port reflection-based amplifier is illustrated in Fig. 2, and was first introduced in [6]. The core of the circuit is a 90° branchline coupler with a 3 dB power split. The incoming high frequency signal is amplified by the RTDs connected to the coupler's ports, and reflected back by the short-circuit discontinuity, and finally summed at the output port. The principle behind this approach is to avoid the need for circulators, which are very difficult to realise at millimetre-wave frequencies. RF chokes and DC decoupling capacitors are used to bias the diodes and provide DC separation from other system components. Finally, the short-circuited stubs TL_1 and TL_2 can be used as tuning elements.

Another approach to building amplifier circuits using RTDs was also investigated and was the distributed active transmission line, a unit cell of which is shown in Fig. 3. The goal is to absorb the junction capacitance C_{j0} of an RTD, together with an inductive element L, in order to achieve a Z_0 of 50Ω [7]. Similarly to the reflection-based circuit, the diodes are biased in the middle of their NDR regions, providing negative resistance, and therefore, gain. The inductance can be implemented either by a lumped element, or through a high-impedance series transmission line stub. In the case of the latter, the impedance and electrical length can be used to fine-tune the circuit.

Both the reflection-based amplifier and the active distributed transmission line designs lend themselves well to use in a multi-stage fashion.

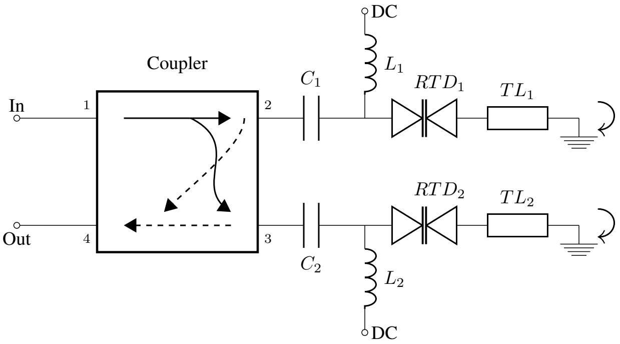


Fig. 2. A diagram illustrating the signal flow in a reflection based RTD amplifier.

In the case of a reflection-based approach, the output of one cell can simply be connected to the input of another cell. Care must be taken to ensure good intra-stage matching and minimise reflections, which could lead to an unstable circuit. On the other hand, the cut-off frequency of the low-pass filter formed by L and C_{j0} is the main limiting factor for the distributed transmission line. Finally, the PVCR of the diodes is the determining factor for the dynamic range of the input signal.

IV. SIMULATION RESULTS

The S-parameters for the RTDs evaluated in this work were obtained through 1-port on-wafer probe measurements. These span the frequency range 30 MHz – 40 GHz, and were performed at various forward and reverse bias levels. After performing preliminary exploration, it was found that the $4\mu m^2$ devices, biased in the middle of their forward NDR regions, had the best performance, and these results are reported in this Section.

The measured data were imported into Keysight Advanced Design System (ADS) for simulation with the two different circuit topologies. The reflection-based design was tested in two configurations, with 1 and 3 RTDs per branch. Results for both are shown in Fig. 4. These illustrate that the usable bandwidth is determined by the coupler, whereas the overall gain and reflection behaviour is heavily dependent on the number of devices used. Depending on system requirements, the circuit can be tuned for low, uniform gain (Fig. 4a) or higher, narrow-band gain (Fig. 4b).

The other amplifying circuit simulated was an active transmission line, matched to $Z_0 = 50\Omega$ line impedance. The circuit consisted of 3 unit cells, and high impedance transmission lines were used to provide the inductance L. The parameters of these interconnecting stubs can be varied to obtain either a low, broadband gain; or alternatively achieve higher gain in a narrower frequency range. Results, shown in Fig. 5 demonstrate a design tuned for centre frequency of 30 GHz, exhibiting around 5 dB gain.

V. CONCLUSIONS & FUTURE WORK

The simulated results at the 25 – 35 GHz range are promising for the use of RTDs as amplifying elements. Immediate next step is to fabricate and measure the simulated circuits in microstrip using commercially available substrates. Concurrently, following successful on-wafer S-parameter measurements up to 110 GHz, work is under way on a W-band amplifier design.

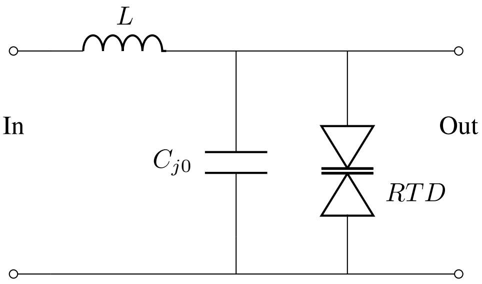
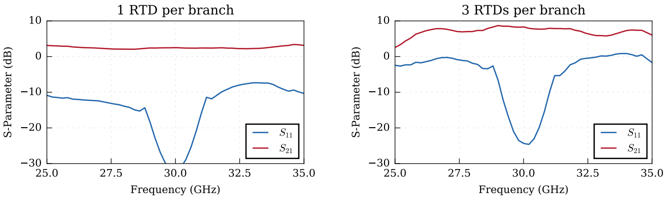
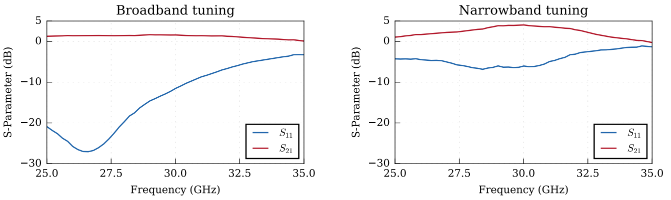


Fig. 3. A single section of a generalised lumped element model of a transmission line.



(a) (b)

Fig. 4. Simulated performance of a reflection-based amplifier with 1 device per branch (a) and 3 devices per branch (b).



(a) (b)

Fig. 5. Simulated performance of a distributed active transmission line amplifier, in broadband (a) and narrowband (b) configuration.

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