Simulation of Amplitude Modulated Resonant Tunneling Diode Oscillator

Citation for the original published paper (version of record):
Josefsson, G., Johansson, C., Fredriksson, V. et al (2026). Simulation of Amplitude Modulated Resonant Tunneling Diode Oscillator. International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz, 2025.
http://dx.doi.org/10.1109/IRMMW-THz61557.2025.11319869

(article starts on next page)

2025 50th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz) | 979-8-3503-7883-2/25/$31.00 ©2025 IEEE | DOI: 10.1109/IRMMW-THz61557.2025.11319869

Simulation of Amplitude Modulated Resonant Tunneling Diode Oscillator

G. Josefsson, C. Johansson, V. Fredriksson, A. Jartun, P. Blomberg, J. Vukusic, and J. Stake
Terahertz and Millimetre Wave Laboratory, Chalmers University of Technology, Gothenburg, Sweden

***Abstract*—Resonant tunneling diode (RTD)-based oscillators have shown promising results in terms of dc-to-rf efficiency and are currently regarded as a viable candidate in enabling terahertz wireless communication. Using a simplified oscillator circuit topology together with a cubic RTD-model we derived the Van der Pol oscillator equation, whose transient response was simulated. The RTD-based oscillator shows clear eye patterns at 50 Gbit/s. However, there appears to be an inherent limitation in the system rise time, restricting the use of amplitude modulation at higher bit rates.**

I. Introduction

THE ever increasing demand for data rate requires the utilization of the THz-region. With fundamental THz-oscillations up to 1.98 THz [1], the resonant tunneling diode (RTD) is a potential candidate for use in wireless link communication systems. Previous work has demonstrated error-free video transmission at a bit rate of 9 Gbit/s at 286 GHz [2], using an RTD-based transmitter and receiver system employing an on-off keying (OOK)-modulation scheme. To support further development of RTD-based transmitters, we investigate the inherent speed limitations of amplitude modulated RTD-based oscillators. Specifically, the maximum bit rate of a single channel OOK-modulated RTD-based transmitter is studied.

II. Method

The simulated system was derived from a simplified RTD-based oscillator, shown in Fig. 1. The RTD was modeled as a constant contact resistance $R_s = 10\ \Omega$ in series with a parallel combination of a voltage controlled current source $i(v_d)$, representing the tunneling current, and a junction capacitance, approximated as $C = \epsilon A/\ell$. Here, A denotes the area of the RTD, while ϵ and ℓ denote the effective permittivity and the total length of the well, barriers and spacer regions, respectively. The tunneling current was modeled with a cubic expression [3] as

$$i(v_d) = -\alpha v_d + \beta v_d^3,\ \alpha = \frac{3}{2}\frac{\Delta I}{\Delta V},\ \beta = 2\frac{\Delta I}{\Delta V^3}, \quad (1)$$

centered in the middle of the negative differential conduction region, where ΔV and ΔI represent the differences between the peak and valley values of voltage and current, respectively, in the dc-IV curve.

Using circuit theory the Van der Pol oscillator equation [4] was derived as

$$\ddot{v}_d - \mu\left(1 - \gamma v_d^2\right)\dot{v}_d + \omega_0^2 v_d = -\delta v_d^3,\ v = v_d + i_d R_s, \quad (2)$$

where the nonlinearity parameter

$$\mu = \frac{\alpha L(1 + GR_s) - GL - R_s C}{LC(1 + GR_s)}, \quad (3)$$

determines the rise and fall time as well as the shape of the waveform generated by the system. The parameter

$$\gamma = \frac{3\beta L(1 + GR_s)}{\alpha L(1 + GR_s) - GL - R_s C}, \quad (4)$$

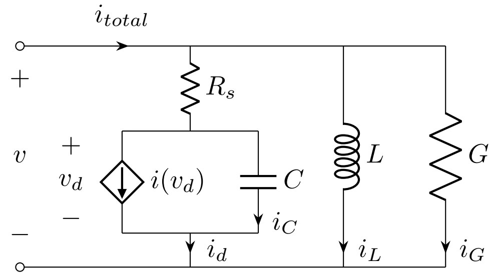

Fig. 1. Equivalent circuit of the RTD-based oscillator.

Tab. I. RTD parameters.

RTD	A [µm^2]	ΔI [mA]	ΔV [V]	μ_{max}/ω_0
No. 1	0.49	1.61	0.26	0.54
No. 2	0.29	0.97	0.52	0.27
No. 3	0.37	1.23	0.72	0.24

acts as a scale factor, whereas

$$\delta = \frac{R_s \beta}{LC(1 + GR_s)}, \quad (5)$$

is a negative feedback coefficient. For a Van der Pol oscillator, the condition for stable oscillation is $\mu \geq 0$ which requires

$$G \leq \frac{\alpha L - R_s C}{L(1 - \alpha R_s)},\ R_s \leq \frac{L(\alpha - G)}{C - \alpha G L}. \quad (6)$$

Therefore, the carrier wave was amplitude modulated by varying the load conductance G as a step function between G_1 and G_0, representing the logic state one and the logic state zero, respectively. The value of G_1 was chosen to maximize the output power at oscillation, which occurs at $G_1 = \alpha/2$ [3], giving $\mu(G_1) = \mu_{max}$. The value of G_0 was selected such that $\mu(G_0) = -\mu(G_1)$, ensuring comparable rise and fall time. The generated carrier wave was set to oscillate around 0.6 THz by choosing the load inductance L to fulfill the relation

$$\omega_0 = \sqrt{\frac{1 - \alpha R_s}{LC(1 + G_1 R_s)}}. \quad (7)$$

Initially the system is at rest, thus energy has to be added to start oscillation. This was incorporated using thermal noise with standard deviation $\bar{e}_n = \sqrt{4kTR\Delta f}$, with the spectral width taken as 0.6 THz.

For the purpose of investigating the system behavior, data from 36 RTDs with an area between 0.26 - 1 µm^2 were considered. Fabrication, measurement details and parameter values are given in [5]. Three RTDs were selected for simulation due to their different values of μ_{max} and are presented in Tab. I.

To assess the limitations of the RTD-based oscillator, the dynamic response of (2) was simulated for different bit rates using a fourth order Runge-Kutta algorithm. This was done by feeding the oscillator a pseudo random bit sequence

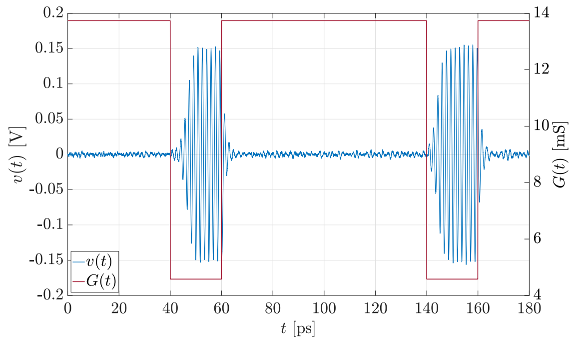

Fig. 2. Input-Output relation. Simulated transient response of the RTD-based oscillator with RTD No. 1 and a bit rate of 50 Gbit/s.

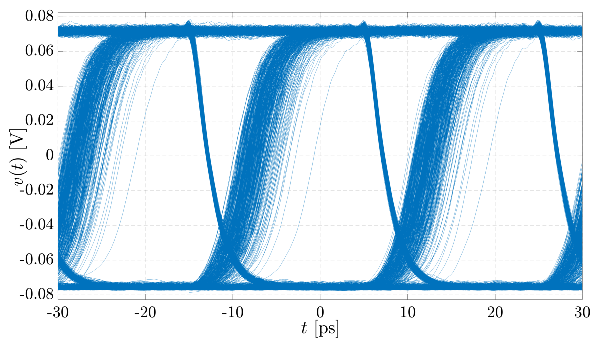

Fig. 3. Eye diagram. Superimposed envelope of the transient response for a 6,000 PRBS with RTD No. 1 and a bit rate of 50 Gbit/s.

(PRBS) of 6,000 bits. The transient signal response was then demodulated and filtered, obtaining the envelope of the signal. Superimposition of three bit sequences of the envelope were visualized as an eye diagram. Furthermore, the eye width and eye height of the three simulated RTD-based oscillators were extracted and plotted as functions of bit rate. The eye width was normalized against its respective bit time and the eye height was normalized against the maximum amplitude of the generated signal.

III. Results and Conclusion

We observe a time constant of approximately 10 ps (Fig. 2), slightly higher than the time constant for a linearized system, $\tau = 2/\mu_{max} = 1.9$ ps – a well-known phenomenon in non-linear dynamical systems such as relaxation oscillators. A clear eye diagram was achieved for bit rates up to 50 Gbit/s when simulating RTD No. 1 (Fig. 3). The jitter in the eye diagram can be attributed to the stochastic nature of the thermal noise used to start the oscillation. At the same time, it is evident that the rise time, from logic state zero to logic state one, is the limiting factor. As the bit rate is increased, apparent degradation of the eye pattern is noted (Fig. 4 and Fig. 5). The parameter μ is observed to affect the rise time of the oscillator, which can be seen in the linearized time constant as well as in Fig. 4 and Fig. 5. Thus, greater non-linearity seem to allow for higher bit rates.

In summary, RTD-based oscillators have limitations in their rise time response, limiting their possible bit rate using amplitude modulation. However, clear eye patterns can be seen at bit

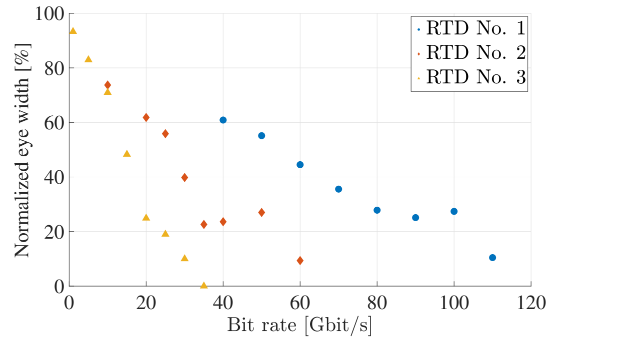

Fig. 4. Normalized eye width. Relative eye width as a function of bit rate for the simulated RTD-based oscillators.

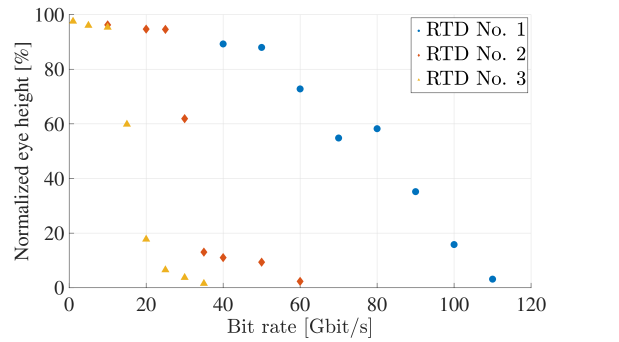

Fig. 5. Normalized eye height. Relative eye height as a function of bit rate for the simulated RTD-based oscillators.

rates of 50 Gbit/s. Additionally, the parameter μ_{max} appears to be a figure of merit for RTD-based amplitude modulation systems. These results support the further development of RTD transmitters for terahertz wireless communication.

IV. Acknowledgments

This work was supported in part by the Swedish Foundation for Strategic Research (SSF), project number CHI19-0027. The authors would like to thank Dr. Gregor Lasser and Prof. Per Lundgren for fruitful discussions.

References

[1] R. Izumi, S. Suzuki, and M. Asada, “1.98 THz resonant-tunneling-diode oscillator with reduced conduction loss by thick antenna electrode,” in *2017 42nd Int. Conf. Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Cancun, Mexico, pp. 1-2, doi: 10.1109/IRMMW-THz.2017.8066877.

[2] S. Diebold *et al.*, “High-speed error-free wireless data transmission using a terahertz resonant tunnelling diode transmitter and receiver,” *Electronics Letters*, vol. 52, no. 24, pp. 1999-2001, Nov. 2016, doi: 10.1049/el.2016.2941.

[3] C. S. Kim and A. Brändli, “High-Frequency High-Power Operation of Tunnel Diodes,” *IRE Transactions on Circuit Theory*, vol. 8, no. 4, pp. 416-425, Dec. 1961, doi: 10.1109/TCT.1961.1086849.

[4] B. van der Pol, “LXXXVIII. *On “relaxation-oscillations”*,” *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, vol. 2, no. 11, pp. 978-992, May 1926, doi: 10.1080/14786442608564127.

[5] P. Blomberg, J. Vukusic, V. Drakinskiy, and J. Stake, “On-wafer characterisation of resonant-tunnelling diodes up to 1.1 THz,” in *2023 48th Int. Conf. Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Montreal, QC, Canada, pp. 1-2, doi: 10.1109/IRMMW-THz57677.2023.10299370.