Chip-Size Resonant-Tunneling-Diode Oscillator as a FMCW and OCT Source

Petr Ourednik[1,*)], Gabriele Picco[1], and Michael Feiginov[1]
[1]Department of Electrical Engineering and Information Technology, TU Wien, Vienna 1040, Austria
*)petr.ourednik@tuwien.ac.at

***Abstract*—We present a chip-size source for FMCW (frequency-modulated continues-wave) radar and frequency-domain OCT (optical coherence tomography) in the sub-THz range. As the source, we use resonant-tunneling-diode patch-antenna oscillators, creating a true chip-size source operating at 680 GHz with an output power of 23 µW. A linearized frequency chirp with a bandwidth of 38 GHz (5.5 %) and 4 mm spatial resolution is demonstrated.**

I. INTRODUCTION

In this paper, we address the behavior of resonant-tunneling-diode (RTD) oscillators [1, 2] regarding their frequency tuning and investigate the possibility of employing the RTD oscillators in THz FMCW radars and OCT applications. The frequency tunability of RTD oscillators was addressed in [3], but never for fast linear frequency chirps. We are using a double-RTD oscillator with a patch antenna forming a true chip-size device. The used RTDs have a nominal barrier thickness of 1 nm. The concept of this oscillator was previously reported [4, 5].

The oscillation frequency of an RTD oscillator is dependent on the bias applied to the RTD, since the RTD depletion-layer and quantum-well capacitances are bias dependent. Therefore, one can use the RTD oscillator as a voltage-controlled oscillator. However, the frequency response of the oscillator is not linear with an applied linear voltage sweep. For FMCW radars, to determine the target's distance and speed reliably, it is required from the source to generate linear frequency chirps.

II. RESULTS

Measured frequency response as a function of the bias voltage of our RTD oscillator is shown in Fig. 1. The inset shows details on the I-V curve zoomed in the oscillation region. The I-V curve contains a contribution of a shunt resistor, that is needed to suppress the low-frequency parasitic oscillations. The oscillation region is between the two hysteresis regions. The continuous line in the frequency plot then corresponds to a fit with a sixth-order polynomial. The data shows two regions of possible operation, before and after the maximum. The first part gives higher tunability range, which was 38 GHz in our case. The second part gives a lower tunability, but an almost constant output power (for our device). We use the first part with a wider frequency range in this work. As the measurement has shown, the shape of the frequency vs. bias curve is not linear. The non-linear frequency sweep would cause a not constant FMCW-detection frequency, hugely decreasing the final resolution.

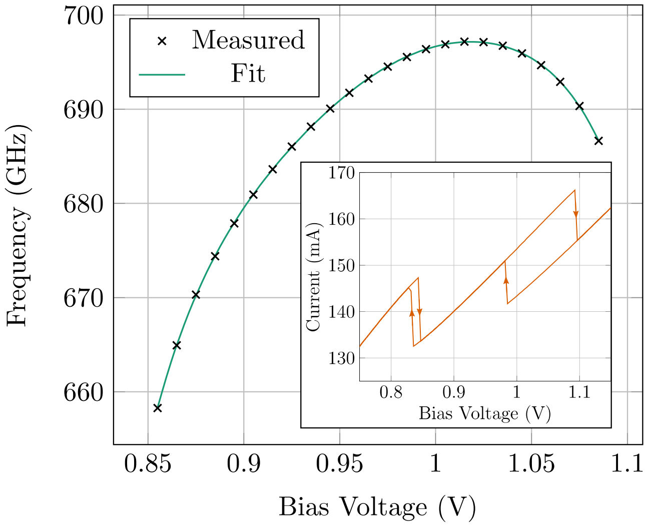

Fig. 1. The dependence of the oscillator operation frequency on the bias voltage. The data are fitted by a sixth-order polynomial. The frequency tuning shows the inflection character. The inset shows the backward and forwards sweeps of the relevant part of the I-V curve in the oscillation range.

To linearize the frequency response in time, one needs to create a non-linear voltage sweep to compensate for the frequency non-linearity. The properly shaped voltage sweep with the duration of 1 ms was generated by an arbitrary waveform generator, it consisted of 50 segments with the duration of 20 µs each. The resulting linearized frequency sweep with the span of 38 GHz is shown in Fig. 2. The frequency-sweep rate is limited by the control equipment, by the external parasitics of the oscillator and by the RTD-resonator properties; the internal (inverse) time constants of RTD itself are in the THz range, they do not impose any relevant limitations. Much faster sweep rates are possible.

A control voltage was applied to the RTD oscillator, which corresponds to a continuous train of saw-tooth linearized frequency sweeps. The modulated RTD oscillator generates a nearly rectangular spectrum with the bandwidth of 38 GHz, which is shown in Fig. 3. A slight deviation of the spectrum from an ideal rectangular shape is due to the bias dependence of the output power of the RTD oscillators [4]. We also note that the spectrum does not contain any subharmonics or spurious lines, that indicates that the RTD oscillator was working in the fundamental mode [4, 5]. The output power of 23 µW was measured by a calibrated pyroelectric detector. The spectrum was measured with an interferometer in the Martin-Puplett configuration and with a Golay cell as detector. The interferometer basically corresponds to a typical OCT measurement configuration; given a linear frequency sweep with rectangular spectrum, the interferogram in Fig. 3 has a sin(x)/x shape, as expected. The peak of the interferogram corresponds to the configuration, when both interferometer mirrors have an equal off-set from the wire-grid interferometer polarizer. The peak width shows a 4 mm OCT resolution, corresponding to the 38 GHz bandwidth of the oscillator frequency sweeps.

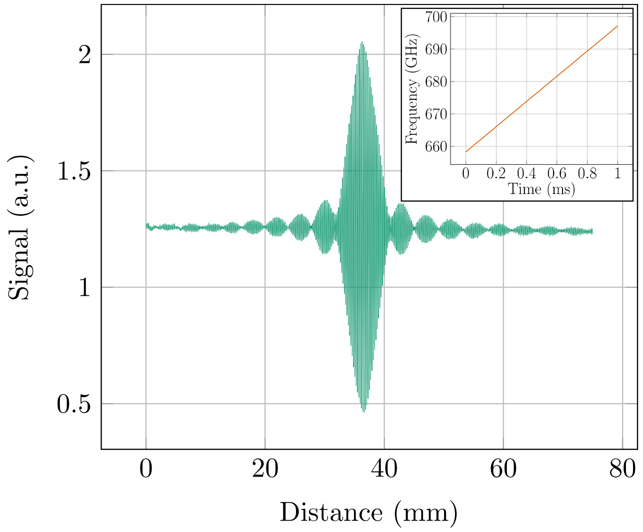

Fig. 2. Measured interferogram of the output oscillator signal with the applied linearized frequency modulation. The period of the sin(x)/x function (OCT resolution) corresponds to half of the reciprocal bandwidth.

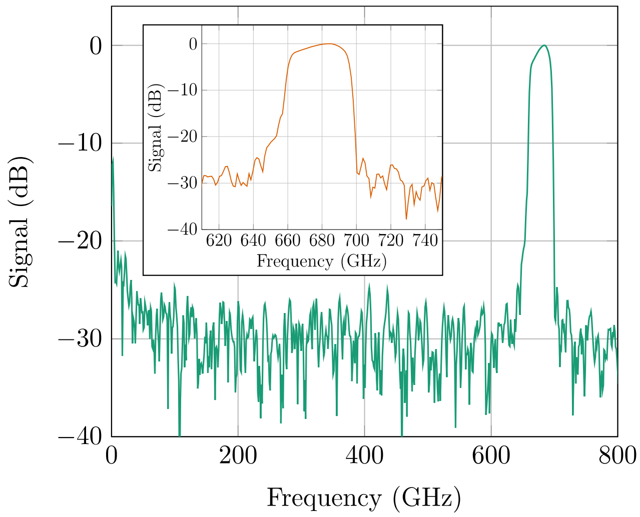

Fig. 3. Measured frequency spectrum of the RTD oscillator with applied linearized frequency modulation. The inset shows a zoom of the operational region.

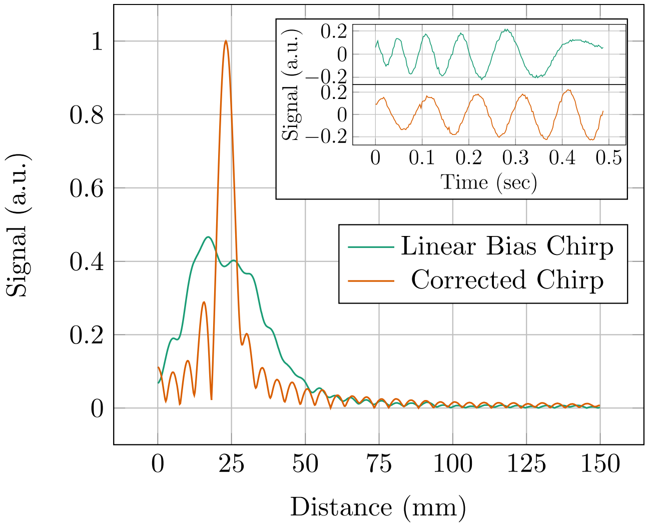

Fig. 4. A detected FMCW-radar signal for the linear bias chirp and the corrected frequency chirp for a target at a distance of 23 mm. The inset shows a time-domain signal for both of the chirps.

To confirm the functionality of the source, we tried to build an FMCW radar. The mutual shift of the mirrors in the interferometer allows one to create two paths with different times of flight. The power detector then mixes the delayed responses due to the square-law detection. The output frequency is then equal to the difference of the input frequencies. The response time of the used Golay cell is 30 ms, and, therefore, for the expected range of the detected frequency, we used a chirp with a duration of 490 ms. Fig. 4 shows a comparison of the detected range plots for a simple linear bias chirp and a corrected chirp linearizing the frequency sweep. The target (static(!) mirror) was at 23 mm. The shape of the curve corresponding to the linear chirp shows a noticeable broadening of the peak, effectively decreasing the resolution and the signal strength. The corrected linearized chirp then shows a clear peak corresponding to the target's distance. The inset shows the signal for both chirps in the time-domain. The linear chirp shows a frequency modulation in time. Meanwhile, the corrected chirps show a sinusoidal signal with a constant frequency.

III. CONCLUSION

In this paper, we demonstrated the possibility of the RTD oscillators as sources for sub-THz and THz FMCW radars and OCT applications. The presented source provides spatial resolution of 4 mm with an output power of 23 µW with an average operation frequency of 680 GHz.

ACKNOWLEDGEMENT

The work was supported by FWF project P30892-N30.

REFERENCES

[1] M. Asada, and S. Suzuki, “Room-Temperature Oscillation of Resonant Tunneling Diodes close to 2 THz and Their Functions for Various Applications,” *Journal of Infrared, Millimeter and Terahertz Waves,* vol. 37, no. 12, pp. 1185-1198, December, 2016.

[2] M. Feiginov, “Frequency limitations of resonant-tunnelling diodes in sub-THz and THz oscillators and detectors” *Journal of infrared, millimeter, and terahertz waves*, vol. 40, no. 4, pp. 365-394, March, 2019.

[3] S. Kitawaga, S. Suzuki, and M. Asada, “Wide frequency-tunable resonant tunnelling diode terahertz oscillators using varactor diodes,” *Electronics Letters*, vol. 52, no. 6, pp. 479-481, March, 2016.

[4] P. Ourednik, T. Hackl, C. Spudat, D. Tuan Nguyen, and M Feiginov, “Double-resonant-tunneling-diode patch-antenna oscillators,” *Applied Physics Letters*, vol. 119, no. 26, 263509, December, 2021.

[5] P. Ourednik, and M. Feiginov, “Double-Resonant-Tunneling-Diode Bridge-Less Patch-Antenna Oscillators Operating up to 1.09 THz,” *Applied Physics Letters*, vol. 120, no. 18, 183501, May, 2022.