Comparison of Measured and Computed Conversion Loss from a Resonant Tunneling Device Multiplier

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Abstract—**The behavior of a resonant tunneling device (RTD) as a multiplier over a range of bias voltages is investigated. The experimental results agree well with large-signal simulations based on a simple equivalent circuit with element values derived from the I–V charactersistic and low-frequency small-signal impedance measurements. This technique can be extended to assist in the design and realization of millimeter and submillimeter RTD multipliers.**

I. Introduction

The strong nonlinearity and associated negative differential resistance (NDR) region in the I–V characteristic of a RTD make it suitable as the basis of a multiplier with a theoretical conversion efficiency significantly higher than the n^{-2} value that applies to resistive multipliers [1]. Such multipliers have been demonstrated [2]–[4].

In this letter, we describe a study performed in our laboratory to investigate the effect of bias voltage on power conversion to second, third and fourth harmonics of the pump signal. The main object was to compare experimental measurements of conversion loss with computer simulations.

II. Experimental

The device used in this study was a 50 μm-diameter double barrier GaAs–AlGaAs RTD fabricated at Nottingham University. Details of its structure have been published elsewhere [5]. Fig. 1 shows the dc I–V and C–V characteristics. The C–V characteristic was determined from small-signal lowfrequency (100 MHz) impedance measurements as described in [6].

The RTD was assembled in a S4-type microwave package. A 50-Ω coaxial system was used throughout and no attempt was made to optimize multiplier performance as the main object of the exercise was to compare computed conversion loss with measurements. The 50-Ω system thus provided an ideally simple and accurate set of embedding impedances for the subsequent calculations.

A sweep oscillator was used to provide a pump signal of 1 mW in the frequency range 0.2 to 1.2 GHz. The packaged device was embedded in a specially designed coaxial mount, while a bias network allowed a dc voltage to be applied across it. The device absorbs part of the pump power and reflects the rest and also generates harmonics that travel along with the reflected wave. A −20-dB coupler then samples the resultant signal that was then displayed on a spectrum analyzer. The reflected power and the power delivered at the various observed harmonics was thus determined. The conversion loss is then simply $P_{\text{out}}(n)/P_{\text{abs}}$ where $P_{\text{out}}(n)$ and P_{abs} are respectively the output power at the nth harmonic and the power absorbed by the device.

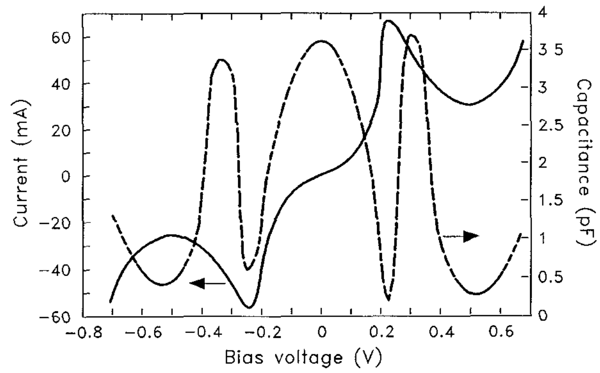

Fig. 1. Intrinsic I–V (solid line) and C–V (dashed line) characteristics of the RTD used in this study.

III. Calculations

The calculations of conversion loss were performed using a multiple reflection technique [7], [8].

Fig. 2 represents the equivalent circuit of a multiplier, including the RTD which is here represented by the familiar tunnel diode equivalent. The embedding network is linear and can be described in the frequency domain by a set of known input impedances. In the multiple reflection technique, this circuit includes a long imaginary transmission line of arbitrary characteristic impedance between the intrinsic device and the embedding network. This effectively divides the circuit into two subnetworks. The first consists of the transmission line and the intrinsic device and is solved in the time domain, while the second contains the line and the embedding impedance (including linear parasitic elements of the device) and is solved in the frequency domain.

Our calculation employs the harmonic balance technique and iterates between the time and frequency domains until the Fourier components of the time-domain voltage and current match those reflected off the embedding network.

The computer program used was based on [8], however the actual experimental data of Fig. 1 (tabulated I–V and C–V measurements) is used to determine the nonlinear device pa-

Manuscript received August 14, 1992.
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IEEE Log Number 9205314.

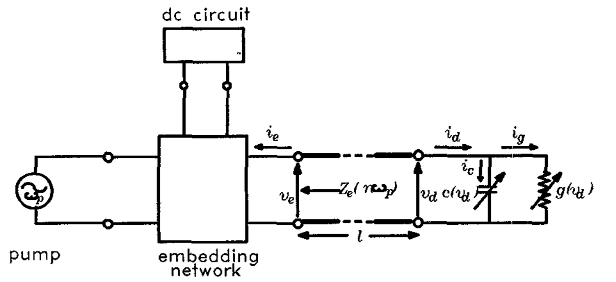

Fig. 2. Equivalent circuit of a multiplier including a simple model for the intrinsic device. The circuit includes a transmission line of arbitrary characteristic impedance Z_0 and length $l = m\lambda$.

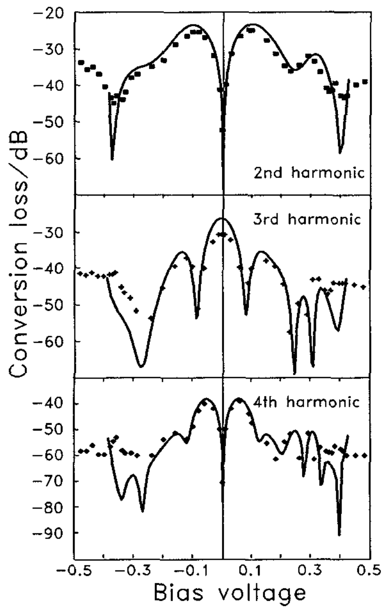

Fig. 3. Measured and calculated conversion loss to second, third and fourth harmonics as a function of bias voltage for a pump frequency of 400 MHz. Solid lines represent calculated values while the points represent experimental measurements.

rameters by cubic spline interpolation during the time domain calculations. A more realistic approximation of the device behavior was thus obtained.

IV. Results

Fig. 3 compares the experimentally observed conversion loss with that computed for the device under test at a pump frequency of 400 MHz. The experimental results are in good agreement with the calculations at bias voltages outside the NDR regions for all the three harmonics considered. The asymmetry between forward and reverse bias is due to a slight asymmetry in the device I–V and C–V characteristics that our program is able to take into account.

The general behavior of the conversion loss is to be expected. At zero bias, the RF voltage spans almost symmetrically about the origin of the I–V characteristic. Thus, the nearly perfect odd-symmetry of the latter leads to an almost total absence of even harmonics from the output, while a relatively strong third harmonic output is obtained.

When the bias voltage is such that the RF voltage lies within the NDR region during some part of the pump cycle, the device is observed to generate spurious oscillations. This is due to generation of relaxation oscillations from low-frequency coupling to the bias circuit (below 45 MHz), since the RF circuit is effectively 50 Ω and the package and mount parasitics are small within the tested frequency range. The present program does not allow for power generation other than at the pump harmonics. It is, therefore, not surprising that measurement and simulation diverge at high bias voltages.

The conversion loss did not vary significantly with frequency.

V. Conclusion

We have measured and calculated the conversion loss to second, third and fourth harmonics as functions of bias voltage of a RTD in a simple multiplier configuration. The results indicate good agreement at biases such that the voltage across the intrinsic device does not enter the NDR region at any point during the pump cycle. As this region is sampled during the cycle the device generates spurious oscillations that appear to downgrade the conversion loss. Since the NDR is valid over a wide frequency range, it is extremely difficult to dc-stabilise a large-area device [9]. However, the case may be significantly different with smaller devices compatible with millimeter-wave operation, where relaxation oscillations may be relatively simple to suppress. In such a situation, we expect a properly optimized system involving a RTD to provide conversion gain.

Simulations based on data from dc and low-frequency small-signal impedance measurements have resulted in accurate large-signal modeling. This technique can be extended to even higher frequencies in the design of novel multiplier structures for millimeter- and submillimeter-wave operation, where there is presently a lack of solid-state devices operating at much above 100 GHz.

Acknowledgment

The authors are indebted to D. P. Steenson, J. M. Chamberlain, and M. Henini of the University of Nottingham for providing the RTD used in this study, in particular to D. P. S. for device processing and packaging and to M. H. for layer growth, which work was made possible by a SERC grant (no. GR/E 91 325).

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