Ofiare, A., Wang, J., Alharbi, K., Khalid, A., Wasige, E., and Wang, L. (2016) Novel Tunnel Diode Oscillator Power Combining Circuit Topology Based on Synchronisation. In: 2015 Asia-Pacific Microwave Conference (APMC), Nanjing, China, 06-09 Dec 2015, ISBN 9781479987658 (doi:10.1109/APMC.2015.7413551)

Novel Tunnel Diode Oscillator Power Combining Circuit Topology based on Synchronisation

Afesomeh Ofiare[1], Jue Wang[1], Khalid Alharbi[1], Ata Khalid[1], Edward Wasige[1] and Liquan Wang[2]

1. High Frequency Electronics Group, School of Engineering,
University of Glasgow,
Glasgow G12 8LT, United Kingdom.

2. Shanghai Electro-Mechanical Engineering Institute,
3888 Yuanjiang Road, Shanghai, China, 201109.

Abstract - **Devices with negative differential resistance (NDR) regions in their current-voltage (I-V) characteristics such as tunnel diodes (TD) and resonant tunneling diodes (RTDs) have been used for realizing high frequency oscillators. In this paper, a new power combining technique is presented which combines output power through synchronisation of two coupled tunnel diode oscillators. The measured output power of the two synchronised tunnel diode oscillators realized in microstrip hybrid technology was -6.72 dBm at 716.2 MHz, while that of single tunnel diode oscillator was -9.09 dBm at 575.7 MHz. The circuit topology proposed in this paper can be utilized to realize high power and high frequency RTD terahertz sources.**

I. INTRODUCTION

Negative differential resistance (NDR) devices especially double barrier structure devices such as resonant tunneling diodes (RTD) with fast switching characteristics have been used to realize solid-state electronic oscillators at room temperature with fundamental frequencies in the terahertz (THz) frequencies range [1]. This brings within reach achieving the potential applications of the THz sources such as biomedical and scientific imaging, high data rate wireless communication and security screening. However, high frequency RTD oscillators exhibit low output power in the micro-Watt range, while milli-Watt output powers are desirable/required.

Power combining techniques have been employed to increase the output power of TD oscillators. Two tunnel diodes in parallel, but with each TD biased individually, were used to realize an oscillator at 450 MHz with reported output power of 0.22 mW [2]. Using this approach, RTD MMIC oscillators with output power around 1 mW at 28 GHz and 75 GHz were also reported [3] [4].

In this paper, we propose a self-synchronized tunnel diode oscillator that consists of two coupled individual oscillators and allows for the combining of their output powers into a single load. Unlike the technique in Refs. [2]-[4] where two devices were used to realize a single oscillator and so the oscillation frequency reduces due to increased device capacitances, here, the output power from two individual TD oscillators is combined to achieve higher power at the same frequency of oscillation. The design can be scaled for higher frequencies by using resonant tunneling diodes in the oscillator design.

II. OSCILLATOR DESIGN

The topology of the single and double tunnel diode oscillator is shown in Figure 1. The decoupling circuit consisting of a parallel connection of resistor, R_S, and capacitor, C_S, is used to isolate the DC bias from the oscillator circuit. R_s is chosen to suppress bias oscillations providing DC stability [2]. The generated RF signal isolated from the DC bias supply by the use of C_S which provides a path to ground. For the synchronized oscillators, each TD in an oscillator has to be decoupled separately and biased individually. Capacitive coupling of both oscillators through DC blocks C_{DC1} and C_{DC2} allows the individual oscillations to get synchronized with the output power delivered to a load, R_{load}.

The RF equivalent circuit of the single tunnel diode oscillator is shown in Figure 2a. The fundamental frequency of oscillation (f_{OSC}) for the single TD oscillator is

$$f_{osc} = \frac{1}{2\pi\sqrt{C_n L}} \qquad (1)$$

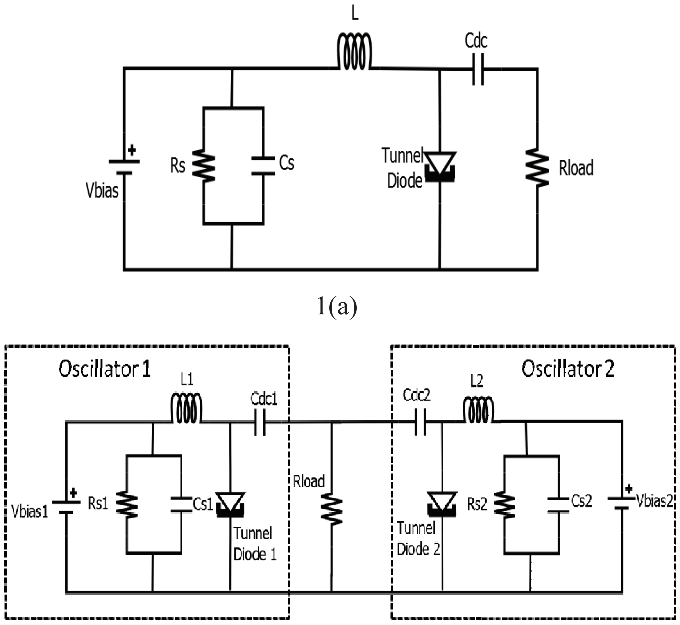
where, C_n is tunnel diode self-capacitances and L the resonating inductance.

For each of the individual oscillators for the synchronized oscillators (Figures 1b & 2b), the oscillation frequency is given by (1). Alternatively, the synchronized oscillator could be considered as a single oscillator with the RF equivalent circuit shown in Figure 2b, where C_{n1} and C_{n2}, are the device self-capacitances, and L_1 and L_2 the corresponding resonating inductances. In this case, the oscillation frequency could be expressed as

$$f_{osc} = \frac{1}{2\pi\sqrt{(C_{n1}+C_{n2})\left(\frac{1}{\frac{1}{L_1}+\frac{1}{L_2}}\right)}} \qquad (2)$$

978-1-4799-8767-2/15/$31.00©IEEE

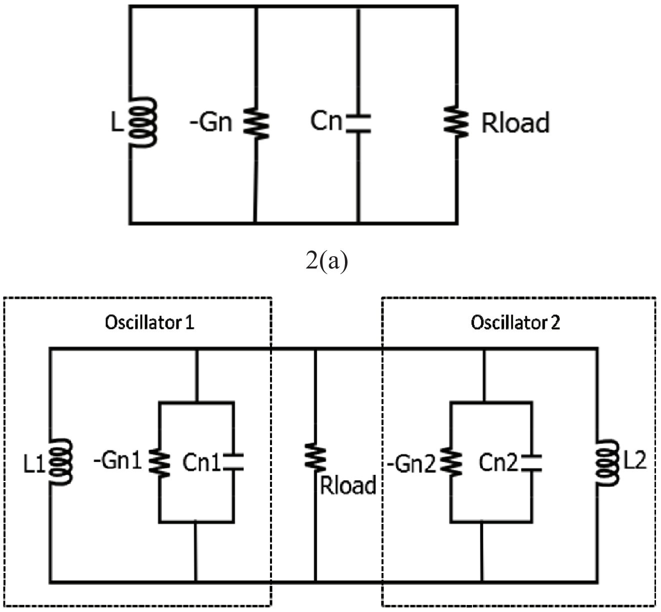
which reduces to (1) for $L_1=L_2 = L$ and $C_{n1} = C_{n2} = C_n$.



1(a)

1(b)

Fig. 1: (a) Single tunnel diode oscillator and (b) power combining topology of two tunnel diode oscillators showing decoupling circuit C_s and R_s, inductance, L and DC block, C_{DC}.



2(a)

2(b)

Fig. 2: RF equivalent circuit of (a) single TD oscillator, (b) synchronized TD oscillators showing: the negative differential conductances and the device capacitances .

III. EXPERIMENTAL RESULTS

The single and double tunnel diode oscillators were realized using a commercially available tunnel diode 1N3717. The 1N3717 tunnel diode has a peak current, I_P of 4.7 mA around 70 mV and valley current, I_V of 0.45 mA at 350 mV. . A series inductance L of 5.5 nH is chosen for both the single and double oscillator circuits. This inductance along with the 1N3717 capacitance, C of 13 pF forms the parallel resonant circuit. These values keep the fundamental frequency of oscillation around 600 MHz, which is within the oscillation frequency range easily attainable by the tunnel diode. The inductances are realized using a 10mm long micro-strip line with width of 1 mm on a Rogers laminate substrate with copper metal thickness of 0.762 mm and dielectric constant, ε_r 3.48. A photograph of the synchronized tunnel diode oscillators is shown in Figure 3. The decoupling circuits described in section II were implemented on the same substrate using a 2 nF capacitor for C_S and a 10 Ω resistor for R_S respectively. The DC blocks were achieved using 3 nF capacitors.

To measure the oscillator performance, DC bias for the TDs is provided to the circuit through the Keysight (formerly Agilent) B2902A precision source/measure unit while the output is connected through a 50 Ω line to a SMA connector which is then fed via coaxial cable to the Keysight E4448A spectrum analyzer. Both oscillator designs showed highest power at 240 mV bias voltage and the output power at the fundamental frequencies are shown in Figures 4a and 4b. The measured fundamental oscillation frequency of the single tunnel diode oscillator presented in figure 4a is at 575.7 MHz with measured output power -9.09/0.12 dBm/mW, while the two synchronized tunnel diode oscillators has a measured fundamental oscillation frequency presented in Figure 4b of 716.2 MHz with measured output power of -6.72/0.21 dBm/mW, which is approximately twice the output power of a single TD oscillator. The variations in the fundamental frequencies of oscillations of the single and synchronized oscillators are attributed to the slight variations in the values of the inductors realized using lengths of micro-strip lines.

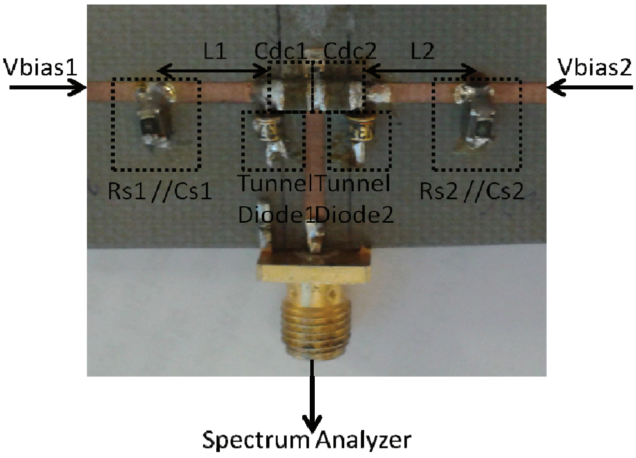
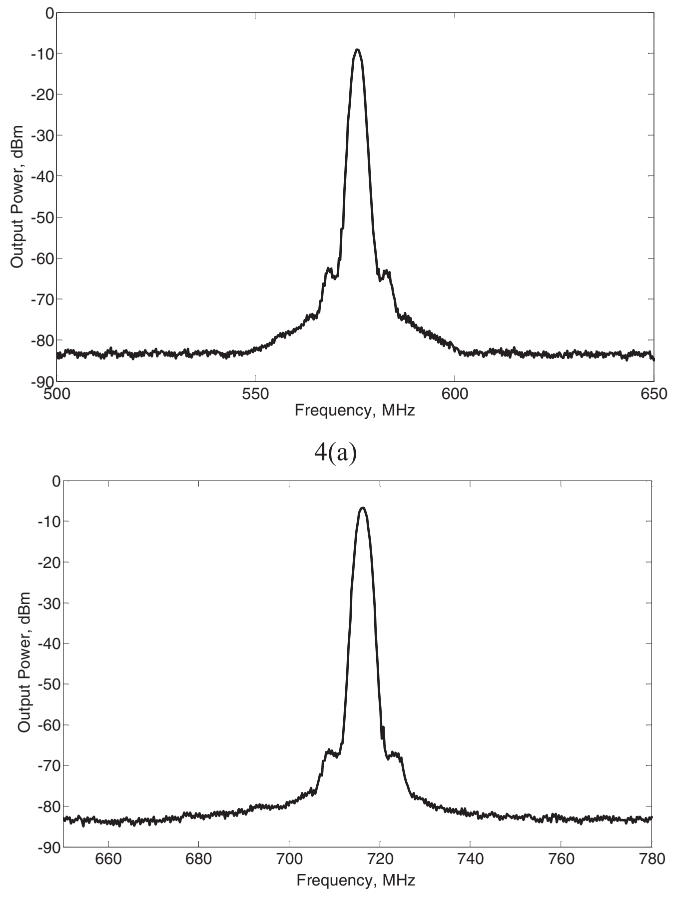


Fig. 3: A photograph of combined two tunnel diode oscillators.



4(a)

4(b)

Fig. 4: Measured spectrum of the fundamental frequencies of: (a) single tunnel diode oscillator with -9.09 dBm output power at 575.7 MHz (b) two tunnel diode oscillators with -6.72 dBm output power at 716.2 MHz.

IV. CONCLUSION

In this paper, a novel self-synchronized TD oscillator design for power combining has been presented. Experimental results shows double the output power compared to a single oscillator design topology. This topology can be scaled to higher frequencies by replacing the tunnel diode in the design with the ultra-broadband resonant tunneling diodes which are capable of oscillating at higher frequencies.

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