An Efficient HBT/RTD Oscillator for Wireless Applications

Héctor J. De Los Santos, Kelvin K. Chui, David H. Chow, and Howard L. Dunlap

***Abstract*—In this paper, we introduce a novel HBT/RTD oscillator suitable for monolithic integration and efficient low power/battery-operated applications. Implementation of a circuit prototype was accomplished by configuring an InP-based monolithic HBT/RTD chip with a gold wire bond inductor in a hybrid microwave package. For an output frequency of 5.8 GHz, the circuit draws a current of 15.5 mA from a 1.5 V supply and generates an output power of $+3.13$ dBm, for an efficiency of 8.84%.**

***Index Terms*—HBT, oscillator, quantum device, resonant tunneling, RTD, wireless.**

I. Introduction

Low power consumption is key to enabling future portable wireless applications [1]–[3]. Because of their small size and radical operating principles, quantum devices (QDs) have demonstrated the potential for highest speed/lowest power-consumption operation [4], and these properties are beginning to be demonstrated in many of the circuit/system functions employing them [5]–[12]. One circuit/system of high importance, but which has received very little attention in the context of its realization based on QDs, is the sinewave oscillator. Sinewave oscillators are at the heart of communications systems, where they are used to establish transmitter carrier frequencies, drive mixer stages that convert signals from one frequency to another, and generate clocking signals [13]. Of particular interest are wireless communications systems such as satellites or portable systems, where low-power consumption and high frequency performance are important. With this context in mind, we focus in this letter on the exploitation of a resonant tunneling diode (RTD), in conjunction with a heterostructure bipolar transistor (HBT), to realize an efficient HBT/RTD oscillator circuit [14].

II. Novel HBT/RTD Oscillator: Circuit, Implementation and Performance

A. Circuit Description

The novel HBT/RTD oscillator circuit shown in Fig. 1(a) was first disclosed in [14]. It consists of an HBT and RTD configured with an inductor in a negative resistance oscillator topology [13]. The supply and bias voltages V_{CC} and V_{BB}, respectively, are so chosen that the HBT is biased at collector current I_{C} and collector-emitter voltage V_{CE} that *set* the RTD DC operating point $(I_{\mathrm{Q}}, V_{\mathrm{Q}})$ in its negative differential resistance region, Fig. 1(b). In turn, $I_{\mathrm{C}} = I_{\mathrm{Q}}$ sets the HBT transconductance which determines the output voltage swing, v_{Out}, across the total collector resistance, $R_{\mathrm{C\_Load}}$, $v_{\mathrm{Out}} \sim g_m v_{\mathrm{BE}} R_{\mathrm{C\_Load}}$ about V_{Q} and, thus, oscillator output power. A small-signal model of the oscillator circuit is shown in Fig. 2, where R_n and C_{RTD} model the RTD, and R_{O} and L_{O} are functions of the HBTs small-signal transconductance g_m, input resistance r_π, output resistance r_{o}, collector node parasitic capacitance C_{cp}, the emitter inductor L and frequency. In terms of these parameters it can be shown that the frequency of oscillation is approximately given by [14]

$$f_{\mathrm{Osc}} = \frac{1}{\sqrt{1+g_m r_{\mathrm{o}}}} \cdot \sqrt{\frac{1 - \frac{(1+g_m r_{\mathrm{o}})\cdot L}{R_n^2 \cdot (C_{\mathrm{RTD}}+C_{\mathrm{cp}})}}{L(C_{\mathrm{RTD}}+C_{\mathrm{cp}}) - \frac{L^2}{r_\pi^2 (1+g_m r_{\mathrm{o}})}}}.$$

This expression will prove useful for future full monolithic implementation of the circuit, as it captures the relation between oscillation frequency and key HBT and RTD device electrical parameters. It also elucidates one important aspect of the HBT, namely, the degree to which the intrinsic oscillation frequency capability of the RTD can be approached, will hinge upon minimizing C_{cp}, or maximizing the HBTs $f_{\max}$ [17]. As indicated by the above formula, and also contemplated in [14], this topology might be implemented with a bipolar junction transistor (BJT) as well.

In addition to its simplicity, the HBT/RTD oscillator introduced here has a number of important advantages over previous RTD-based oscillators [4]. For instance, it consumes much less power, as much as 90% less, than known feedback oscillators. Indeed the single supply V_{CC} can be much lower, for example 1.3 V because it must only supply the voltage drops across the RTD, which may be as low as 0.1 V [15], [16], the HBTs active region collector-emitter, and the inductor L. This not only extends the life of the battery, but also allows a smaller battery, suitably 1.5 V, to be used. Also, unlike the known negative resistance waveguide oscillators [4], the HBT/RTD oscillator is suitable for monolithic integration, using either the III-V compound technology currently used for RTDs or the silicon or gallium-arsenide technology used for HBTs. Although the HBT/RTD oscillator consumes slightly more power than the waveguide oscillator and has a lower quality factor, the size, cost, reliability, and reproducibility advantages associated with monolithic integration more than offset these disadvantages. Alternatively,

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H. J. De Los Santos was with Hughes Space and Communications Company, Los Angeles, CA 90009 USA. He is now with COVENTOR, Inc., Irvine, CA 92606 USA.

K. K. Chui was with Hughes Space and Communications Company, Los Angeles, CA 90009 USA. He is now with Boeing Satellite Systems, Inc., El Segundo, CA 90245 USA.

D. H. Chow and H. L. Dunlap are with the HRL Laboratories, LLC, Malibu, CA 90265 USA.

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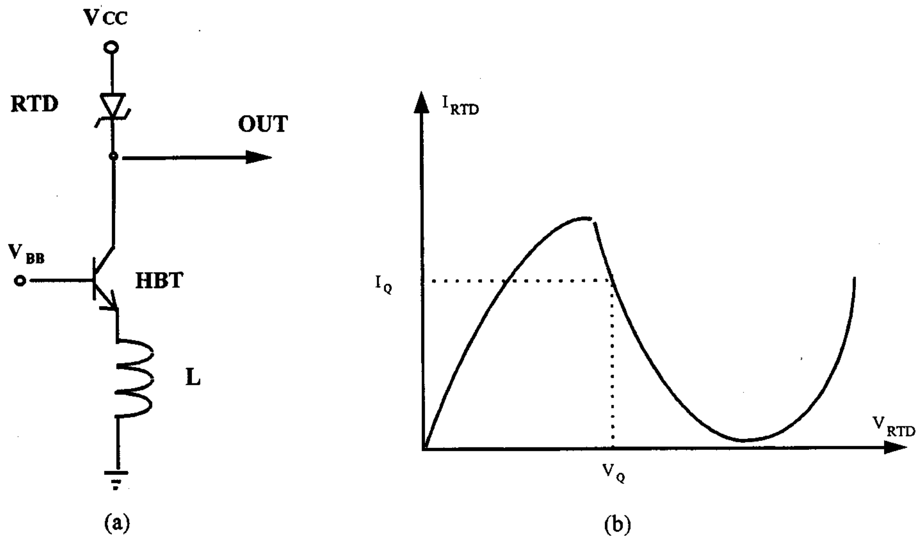

Fig. 1. (a) HBT/RTD oscillator circuit and (b) RTD dc bias condition.

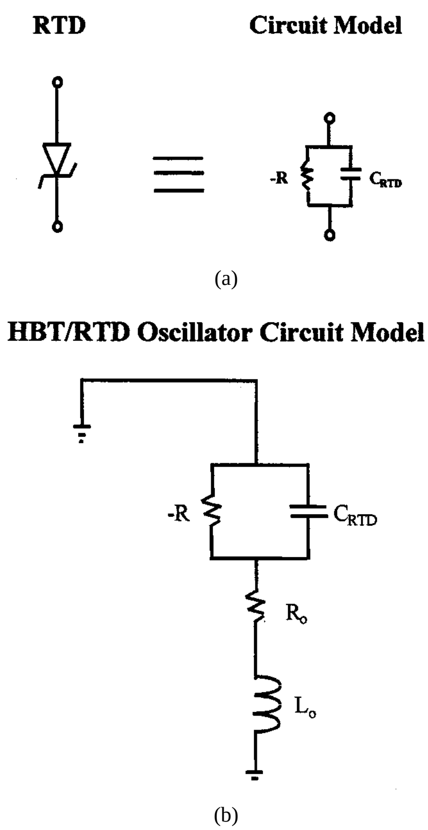

Fig. 2. (a) RTD circuit model and (b) HBT/RTD oscillator small-signal circuit model.

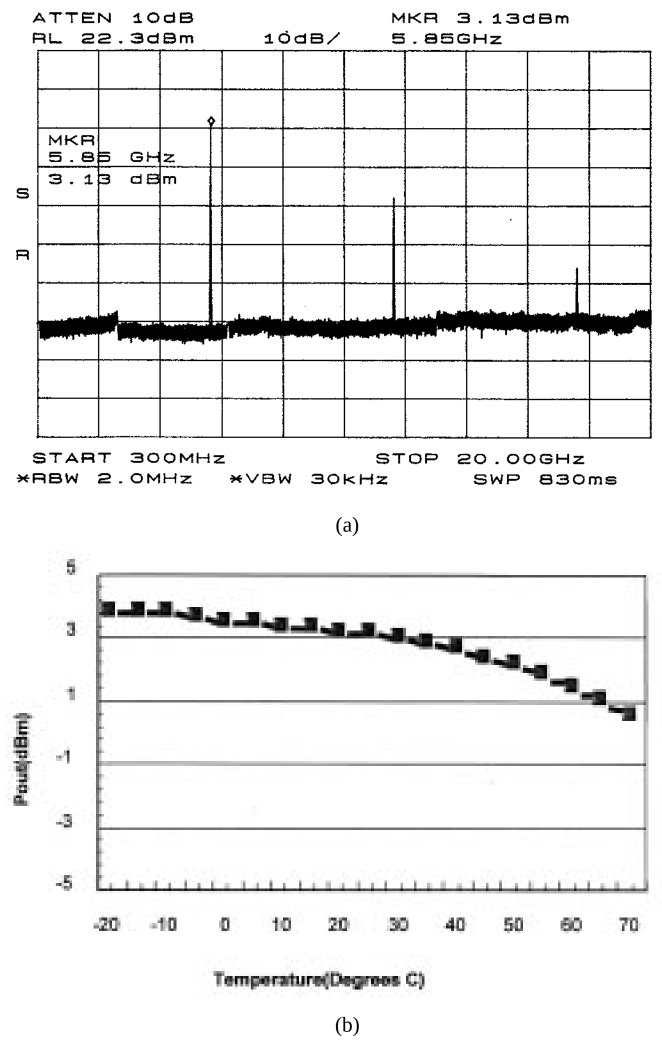

Fig. 3. HBT/RTD oscillator performance: (a) room temperature output spectrum and (b) output power versus temperature.

the RTD and HBT can be fabricated in discrete chips, which is still cheaper, more reliable, and easier to mass produce than the waveguide oscillator.

B. Implementation and Performance

An indium phosphide (InP) based technology was used for the implementing the active part of the circuit. $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ heterojunction bipolar transistors (HBTs) were monolithically integrated with $In_{0.53}Ga_{0.47}As/AlAs/InAs$ resonant tunneling diodes

(RTDs) in a coplanar geometry. The epitaxial layers for the two device structures were deposited in a single growth run by molecular beam epitaxy on an InP wafer which is patterned by photolithography and dry etching prior to growth. The substrate pattern consists of pedestals, which support RTDs after postgrowth device fabrication, and a lower level which ultimately supports HBTs. Details of the integration process have been reported elsewhere. [16] HBTs fabricated in this process have typical current gain of 40–60 and unity gain cutoff frequencies approaching 100 GHz. The RTDs were designed to yield a peak current density near 5×10^4 A/cm^2, with a peak-to-valley current ratio of 10 and a peak voltage position of 0.3 V. The HBT/RTD chip was die-attached using Silver epoxy to a 450 square mil ceramic package [12]. The device contacts were wire bonded to dc bias pads and the inductor was realized with a Gold wire of 1 mil diameter and a length of approximately 130 mils. Fig. 3 shows the measured oscillator performance for the hybrid circuit prototype. With a supply voltage of 1.5 V, the circuit draws a current of 15.5 mA and delivers an output power of $+3.13$ dBm, Fig. 3(a); this equates to DC efficiency of 8.84%. The temperature performance of the intrinsic HBT/RTD oscillator, i.e., with no attempt made at temperature-compensation, Fig. 3(b), reveals an output power variation of -0.037 dBm/°C between $-20\,^\circ$C and $+70\,^\circ$C. Future work will address noise performance.

III. CONCLUSION

We have presented the description, implementation, and output power and efficiency performance of a novel [14] HBT/RTD oscillator circuit suitable for *monolithic* integration and low-power/battery operated wireless applications. In particular, the circuit has the potential to exploit the high-frequency/low-power characteristics of the RTD within a monolithic context and thus opens the way for insertion in high-volume applications.

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