ANALYSIS OF WAVEGUIDE IMPATT OSCILLATOR CIRCUITS

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ABSTRACT

The Kurokawa oscillator theory is applied to IMPATT oscillator circuits using an accurate non-linear diode equivalent circuit and broadband circuit representations of both rectangular and coaxial waveguiding structures. The analysis considers the influence of harmonic components in the oscillator output.

Introduction

The theory of solid-state oscillators in microwave circuits is based on the work of Kurokawa[1] who showed that oscillator characteristics such as stability, parasitic phenomena and noise could be determined from the intersections on an impedance plane, of a device line (representing the device impedance as a function of amplitude) and a circuit line (representing circuit impedance as a function of frequency).

The assumption of Kurokawa, that the device impedance is frequency-invariant, was removed by Eddison and Howes[2], who consequently obtained a device surface in a frequency-impedance space, with oscillator behavior determined by the intersection of the circuit line with this surface.

Application of this theory to IMPATT oscillator design has generally involved measurement of the device impedance as a function of frequency and amplitude, rather than its computation from IMPATT theory, due to the inaccuracy of the small-signal impedance expressions and the complexity of large-signal expressions. Circuit impedance has also generally been measured using a probe structure, rather than by computation. As a result, the Kurokawa theory has been used mainly to obtain only an approximate indication of oscillator performance, and its full potential in IMPATT oscillator design has not been explored.

This paper provides a technique for full application of the Kurokawa approach to the IMPATT oscillator, at fundamental and harmonic frequencies, using an accurate non-linear equivalent circuit for the device in conjunction with broadband representation of the passive circuit.

IMPATT Oscillator Analysis

The IMPATT device representation is based on the analysis of Kuvas and Lee[3], which considers carrier diffusion, unequal hole and electron ionization rates, and unequal hole and electron drift velocities. A general non-linear circuit, developed by Gannett and Chua[4] from the Kuvas and Lee analysis, is shown in Fig. 1.

The approach adopted here begins with the nonlinear terms in this equivalent circuit being represented by a power-series expansion in powers of the avalanche voltage V_a. Using an estimate of the fundamental and harmonic components of V_a, together with the expressions of Steer and Khan[5] applied to the power-series expansion, a value is found for the avalanche current I_a. With fundamental and harmonic components of I_a found, the overall device voltage and current can be determined, and hence its impedance Z_d at the fundamental and harmonic frequencies. Note that these device impedances are a function of V_a values at fundamental and harmonics.

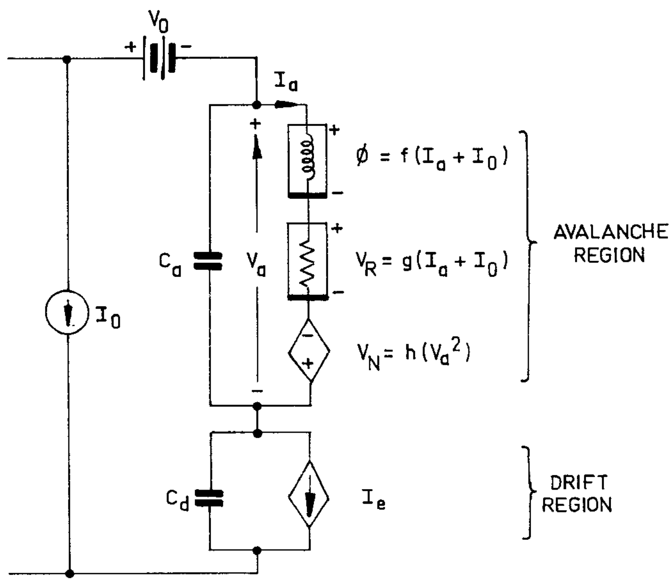

Figure 1: IMPATT diode equivalent circuit (after Gannett and Chua[4]).

With the external circuit impedance represented by Z_c, the expression given by the sum of $|Z_c + Z_d|^2$ over fundamental and all harmonics is minimized by variation of the V_a components, using a Fletcher-Powell minimization technique, which involves determining analytical expressions for the derivatives of the impedance components with respect to frequency and to the magnitude and phase of the V_a components. The minimum value of the total impedance expression is equal to zero, giving an oscillation condition. Using the previously-determined derivatives, the oscillation condition is then tested for stability by application of the extended Kurokawa criteria of Brackett[6].

The approach outlined above has been applied to IMPATT oscillator circuits in both rectangular waveguide and coaxial line. The diode characteristics are identical to a GaAs diode described by Schroeder and Haddad (diode #1)[7]. The package is represented by a standard low-pass π-network.

Application to X-Band Waveguide Circuit

The X-band waveguide circuit is shown in Fig. 2(a). The broadband equivalent of the diode mount was found using the expressions of Eisenhart and Khan[8]. Fig. 2(a) also shows the effect of variation in the diode package inductance on oscillator frequency, while Fig. 2(b) shows the corresponding variation in output power for two different short-circuit positions. As expected, increasing the package inductance lowers the oscillation frequency. However the effect on power output depends on the position of the short-circuit plane. Fig. 3 shows the effect of the short-circuit position for a fixed value of package inductance of 0.6 nH.

The output power is particularly sensitive to short-circuit position while the frequency is tunable over only a small range. This indicates the unsuitability of a straight post-in-guide IMPATT diode mount and the need for other structures to provide fundamental and harmonic resonances for the diode e.g. resonant cap structures.

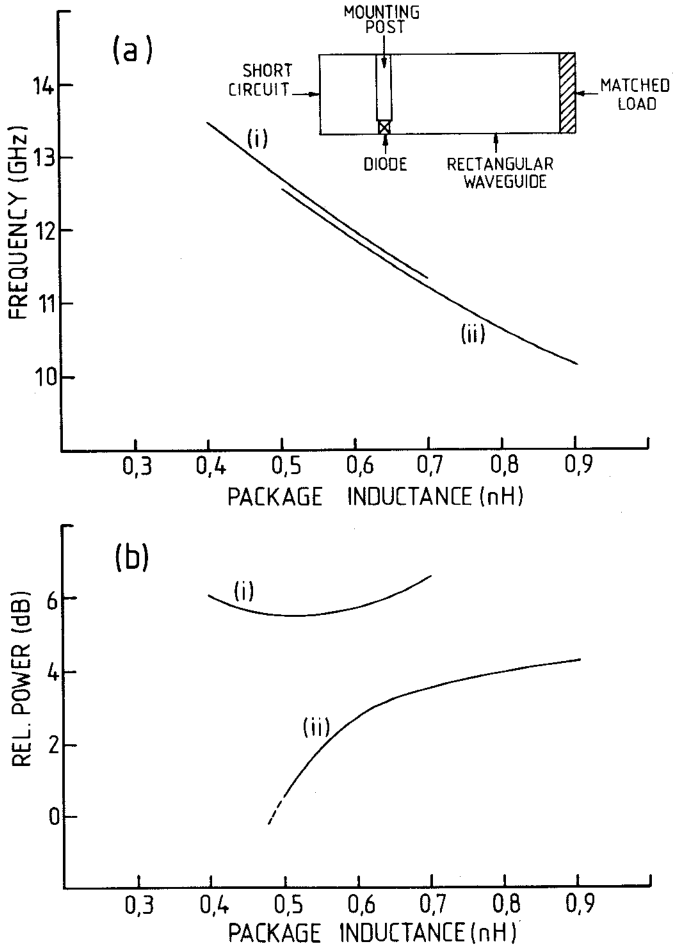

Figure 2: Variation of (a) frequency and (b) power output of IMPATT oscillator as a function of diode package inductance. Curve (i) is for a short circuit position of 1.9 cm while curve (ii) is for a short circuit postion of 2.5 cm. The inset shows the oscillator circuit.

Application to Coaxial Circuit

An Iglesias[10] circuit for studying the effect of harmonics on oscillator performance is shown in Fig. 4(a). The circuit used here was designed so that the first slug (nearest the diode) would be transparent at 22 GHz while the second (composite) slug would be transparent at 11 GHz. A six-element broadband diode package representation was used[9]. Results obtained with this circuit are shown in Figs. 4 and 5. Fig. 4 shows the effect of moving the first slug while keeping the position of second slug fixed (D_2 = 17.16 mm). The fundamental power (Fig. 4(b),(i)) varies reasonably smoothly over the tuning range. However the power output at the second harmonic, although fairly constant over the range 9.55 to 9.95 mm, shows a rapid decrease for D_1 less than 9.55 mm. This is associated with an increase in the fundamental frequency brought about by a change in diode-circuit interaction at the second harmonic.

Tuning the second-harmonic by movement of the second slug results in the curves shown in Fig. 5. If

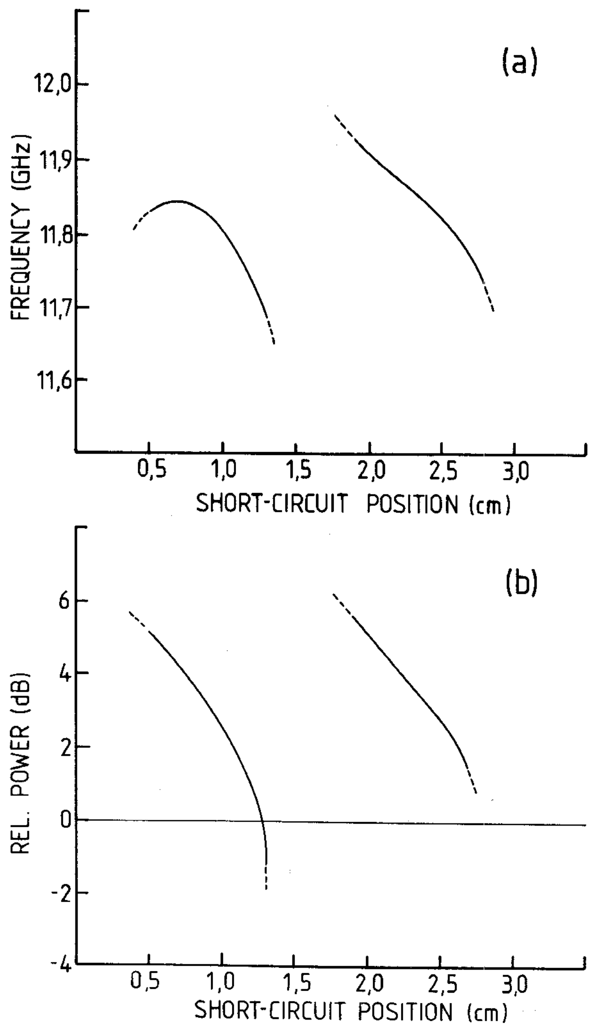

Figure 3 Variation of (a) frequency and (b) power output as a function of short circuit postion, for 0.6 nH package inductance.

only the fundamental is considered in the analysis the dashed curve results, showing nearly constant power output and a small change in frequency. However if the second harmonic is included, the results obtained are markedly different for D_2 less than about 17.1 mm. For D_2 between 16.97 mm and 16.94 mm there are two possible stable solutions to the oscillator equations. Although the fundamental power output values for these two solutions are only slightly different, the level of second-harmonic power varies by as much as 10 dB. Thus this circuit demonstrates hysteresis in the oscillator tuning characteristics of the form often observed in practice.

Conclusions

This paper reports an analysis method for IMPATT oscillator circuits, capable of predicting a wide variety of device-circuit interactions including harmonic effects. The method has been applied to both rectangular waveguide and coaxial line structures.

Acknowledgements

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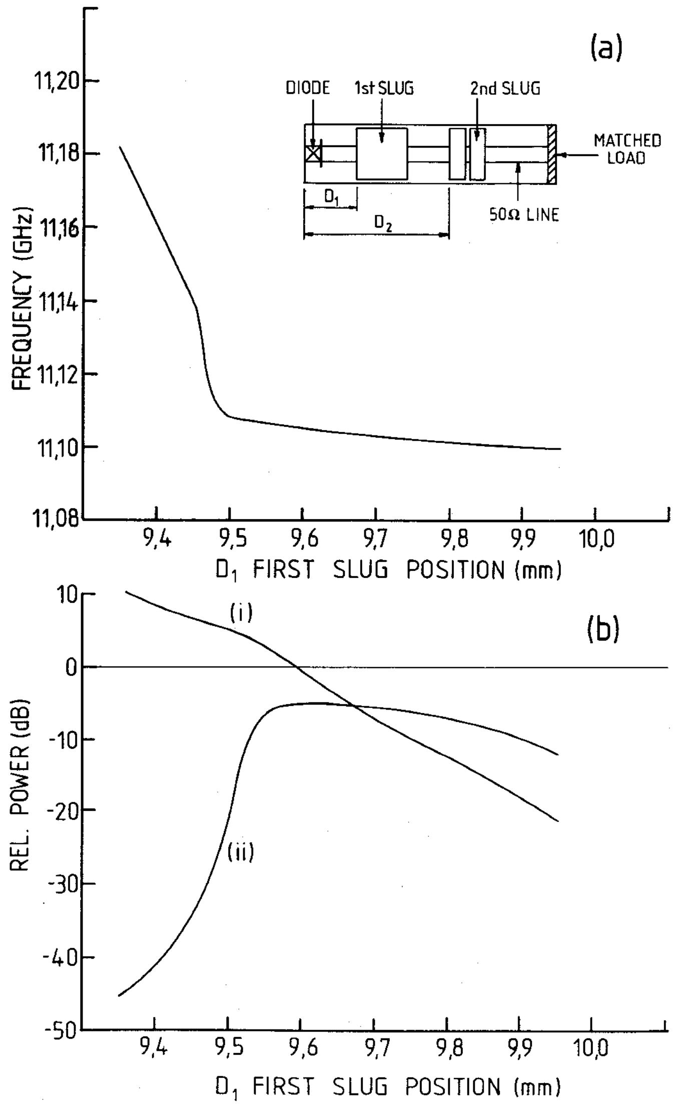

Figure 4: Variation of (a) fundamental frequency and (b) output power as a function of first slug position. Curve (i) is the fundamental output power and curve (ii) is the second-harmonic output power. The inset shows the oscillator circuit.

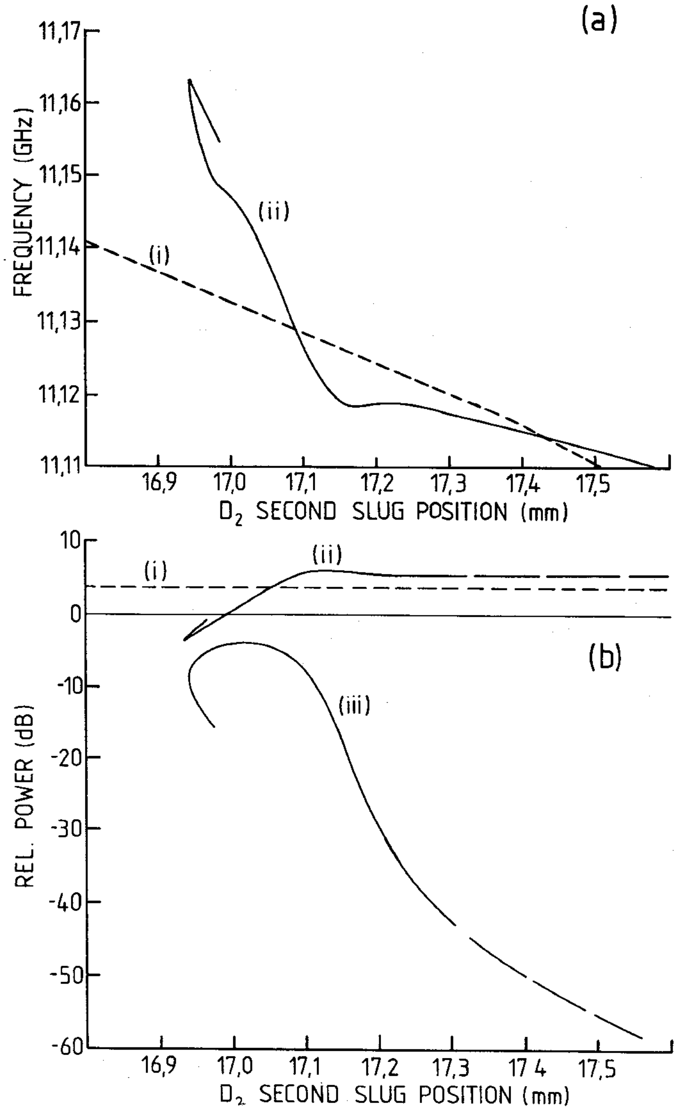

Figure 5: Variation of (a) frequency and (b) power output as a function of second slug position. Curve (i) is for the fundamental if the effect of the second-harmonic is neglected, (ii) is for the fundamental with the second harmonic included and (iii) is the second harmonic output power.

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