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ANALYSIS AND USE OF HARKLESS DIODE MOUNT FOR IMPATT OSCILLATORS

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Summary

An equivalent circuit is derived for the Harkless diode mount used in IMPATT oscillators and the Kurokawa waveguide combiner. Comparison with experimental measurements of the authors and other workers shows that this equivalent circuit is accurate for a wide range of conditions, including multimode waveguide propagation and the diode off-center in the guide. This equivalent circuit is directly applicable to IMPATT combiner studies and is used in a recently-developed oscillator analysis technique to accurately predict oscillator frequency and power output and to examine second-harmonic tuning in the Harkless oscillator circuit. The results are supported by experimental evidence.

Introduction

This paper presents a circuit model of the structure which forms the basis of the waveguide combiner circuit invented by Harkless[1] and popularized by Kurokawa.[2,3] There is a pressing need for an accurate equivalent circuit for this structure, to facilitate the design of single-diode oscillators and of power combiners.

Eisenhart established an equivalence between a coaxial entry to waveguide and a gap in a post in guide by an empirical approach.[4] Although it can be used in conjunction with a two-gap diode mount approach[5] to obtain an equivalent circuit for the Harkless mount, the empirical approach restricts its usefulness and accuracy.

The most useful equivalent circuit to date has been that of Chang and Ebert,[6] based upon the Lewin analysis[7] of posts in waveguide. Their equivalent circuit agrees reasonably well with measurements by Eisenhart[5] at X-Band. However the agreement is open to considerable improvement, especially as they only consider the case of matched loads on both waveguide ports, the easiest case to model. Their model suffers from the well known deficiency of the Lewin approach - representation of the coaxial aperture by a delta-function load at the base of the post, leading to an infinite series which is then truncated. This infinite series converges very slowly and the point at which it should be truncated is not known.

This paper sets out an accurate approach to equivalent circuit determination, which is verified by experimental measurements. It is a significant improvement over previous models. The accuracy of the model allows it to be used to examine the performance of an IMPATT oscillator based on the single diode structure and augurs well for the modeling of a multi-diode combiner.

Structure and Model

The structure being modeled is shown in Figure 1. It consists of a coaxial line cross-coupling to waveguide. One end of the coaxial line is normally terminated in an absorbing material producing a matched load. An IMPATT diode may be placed at the other end of the coaxial line, usually via a quarter-wave matching section, as a source of power. Power couples from the coaxial line to the waveguide, and the output is taken on one waveguide port with a movable short on the other port for tuning. This structure forms the basis of the Kurokawa power combiner in which these modules are placed close to the waveguide walls and spaced one-half wavelength down the guide.

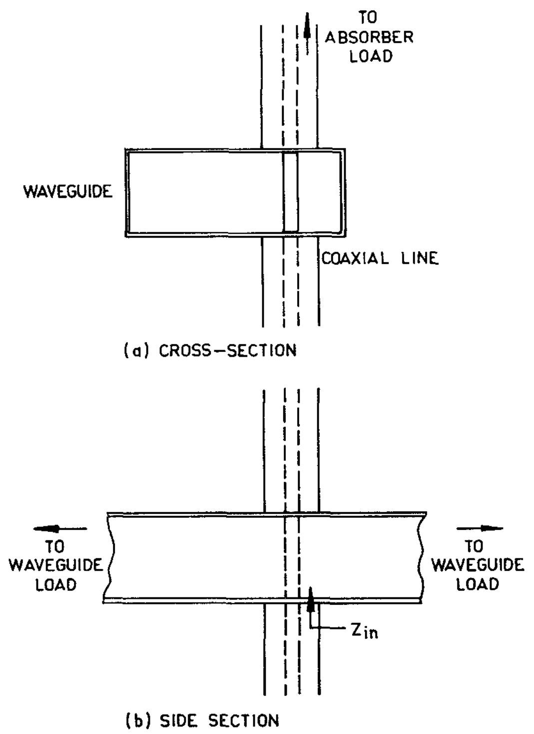

Figure 1: The Harkless diode mount.

A general equivalent circuit is derived for the Harkless mount, based upon an image theory approach to coaxial-line-to-waveguide junctions formulated by Williamson.[8,9] He used a simpler structure in which one end of the coaxial line is shorted at the broadwall of the waveguide and both waveguide ports are terminated with a matched load. The structure is considered to be excited by a magnetic current frill located in the coaxial line at the plane of the other broadwall of the waveguide. Image theory is then used to obtain an infinite array of images of the structure. The current distribution on the inner conductor of the coaxial line, and the electric and magnetic fields near the inner conductor are obtained from the summation of the infinite series resulting from the images along with the appropriate boundary conditions. The input impedance looking along the coaxial line at the waveguide broadwall boundary is then obtained from the field expressions.

The expression for the input impedance can be extended, to the case where the coaxial line is not shorted but has an arbitrary load, simply by superposition. Inclusion of an arbitrary load is of practical interest, as the Harkless oscillator circuit can be optimized with a mismatched coaxial termination.[10]

If an arbitrary load is allowed on the waveguide ports, the expression for the impedance must be manipulated, so the coupling from the coaxial line to the various waveguide modes becomes explicit. This is not straight forward, as the infinite series in the impedance expression relates to the various images and not explicitly to the various waveguide modes.

We extended Williamson's approach to accommodate up to three modes propagating in the rectangular waveguide (in contrast to the single mode propagation of Chang and Ebert). This extension is vital since:

(a) The mount is normally used with a waveguide short close to the post; hence higher-order evanescent-mode coupling will occur between post and short-circuit termination;

(b) IMPATT oscillator performance is affected by harmonic impedance terminations, which are beyond the dominant waveguide-mode frequency range;

(c) The equivalent circuit needs to be applicable to the power-combiner structure, where higher-mode coupling between posts will occur.

The equivalent circuit hence accommodates arbitrary loads on the coaxial port and on both waveguide ports. The inclusion of up to three modes allows it to be used to about 16 GHz for X-Band guide. The three-mode equivalent circuit is shown in Figure 2. Including an even higher number of waveguide modes complicates the model excessively, and is not considered worthwhile.

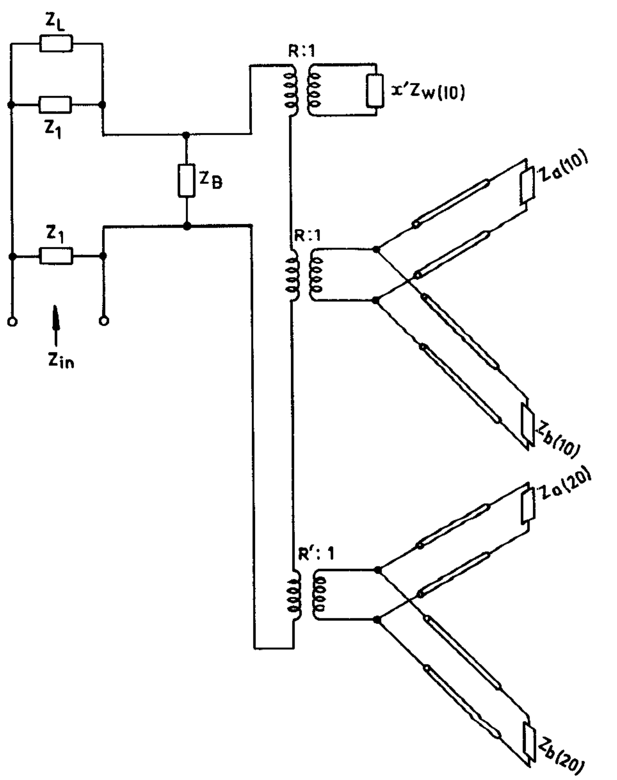

Figure 2: Three-mode equivalent circuit of the Harkless mount.

Comparison with Measurements

Figure 3 shows a comparison of Eisenhart's[5] measurements, Chang and Ebert's model[6] (as computed by the authors) and the new model for the simplest case of a centered post and all output ports matched. The new model is seen to match the measurements very closely. Figure 4 shows the comparison for a similar structure, but with a variable short on one waveguide port, using measured values taken by the present authors. Figure 5 shows the case for a similar structure, but with the post now located one-quarter of the distance across the guide; once again the new model is clearly superior. We carried out a wide range of measurements for a variety of post positions, waveguide terminations, etc., and in all instances our model gave impedance values distinctly closer to the measured values than any other model. Published experimental measurements of others, such as Eisenhart (who also includes variable post size), further confirm the superiority of our model.

An oscillator was constructed by replacing the impedance measuring set by a 10Ω impedance transformer and an IMPATT diode mounted on a heat sink. Measurements of oscillator frequency, power output, and circuit efficiency, as a function of short-circuit position, were compared with analysis results obtained using the equivalent circuit together with the oscillator analysis approach of Bates and Khan.[11] Figure 6 shows the excellent agreement obtained; the results verify the accuracy of the equivalent circuit and oscillator analysis approach.

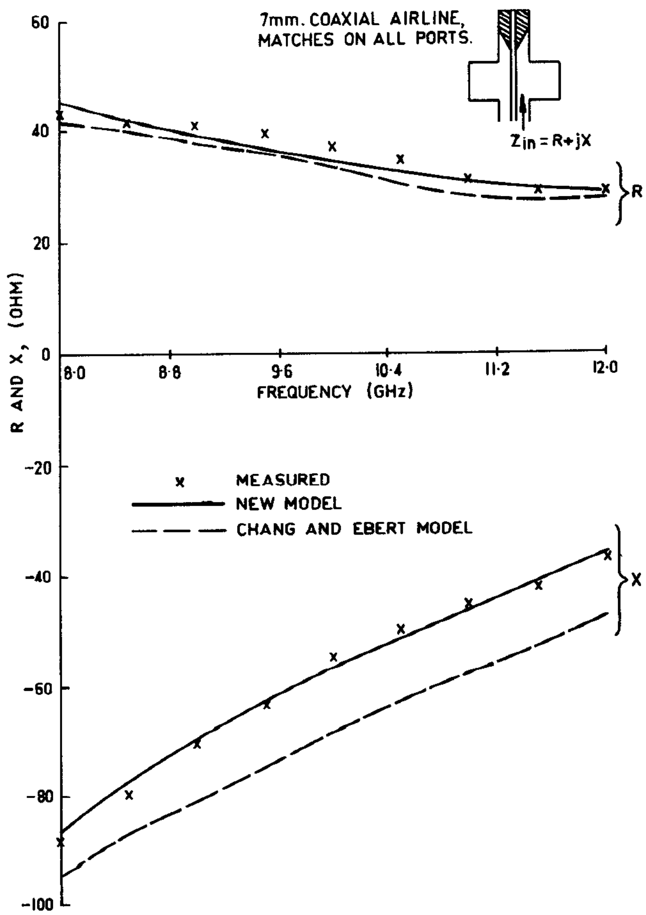

Figure 3: Comparison of calculated and measured input impedance for the Harkless mount, with a centered post and with all output ports matched.

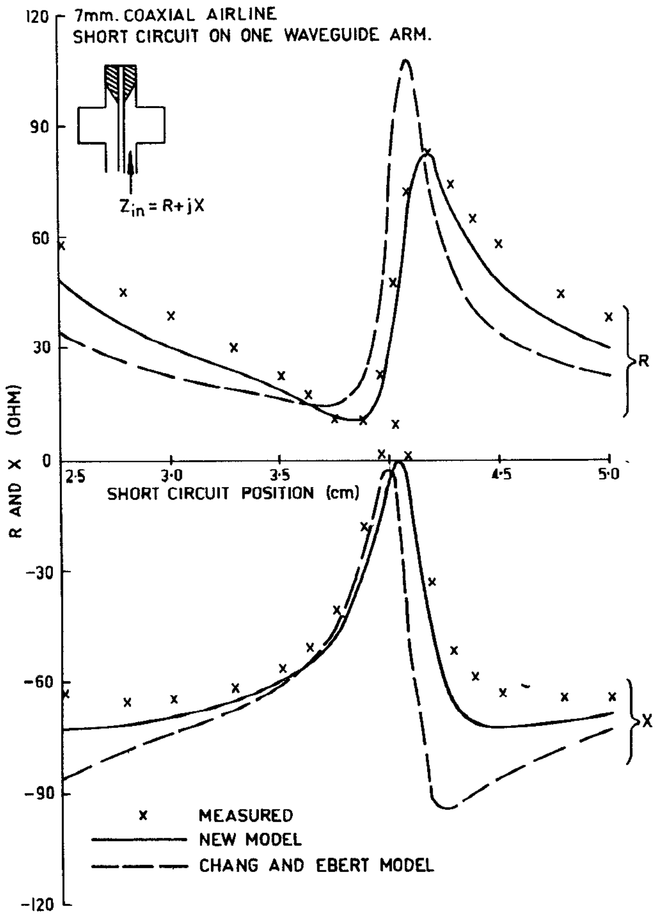

Figure 4: Comparison of calculated and measured input impedance, with a centered post and a variable short-circuit on one waveguide port. Frequency is 10 GHz.

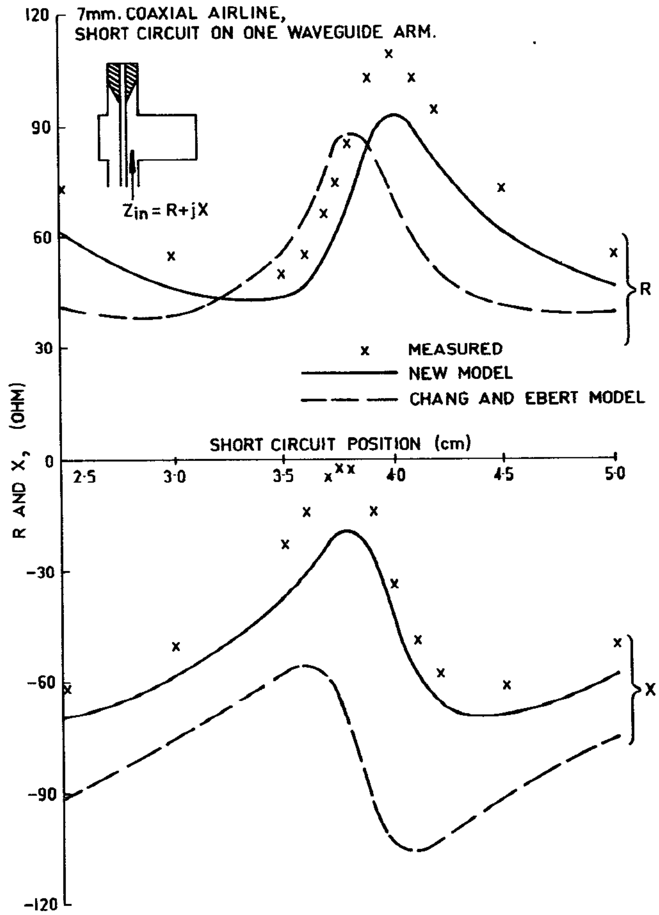

Figure 5: Comparison of calculated and measured input impedance, with the post one-quarter of the distance across the guide, and a variable short-circuit on one waveguide port. Frequency is 10 GHz.

Second-harmonic Tuning Effects

The importance of second-harmonic tuning effects in IMPATT oscillator behaviour has long been recognized,[12,13] particularly the improvement in power output which may be gained at frequencies below the transit-time frequency with appropriate second-harmonic loading. However, theoretical studies of this effect have been largely confined to simple resonant-circuit representations of the oscillator circuit.[13,14] Second-harmonic tuning effects resulting from a mismatched coaxial termination in the Harkless oscillator circuit have been examined. It is well known that the termination on the coaxial port opposite the diode significantly affects the output power and circuit efficiency,[6] and the circuit may be optimized with a mismatched termination.[10] However second-harmonic effects have not hitherto been studied. Figure 7 shows the fundamental frequency and the fundamental and second-harmonic powers delivered to the waveguide load and to the coaxial termination of 75Ω (in the 50Ω line) as a function of the distance of the mismatched termination from the waveguide wall. The result demonstrates that at this frequency (below the transit-time frequency), the fundamental power output is greater when the second-harmonic interaction is large.

Conclusion

A general multimodal equivalent circuit of the Harkless mount has been presented which is demonstrably more accurate than any other model previously available. The oscillator results presented show the accuracy and usefulness of the equivalent circuit in predicting frequency and power output and in the study of other effects such as second-harmonic tuning. This equivalent circuit should pave the way for an accurate model of the Kurokawa waveguide combiner.

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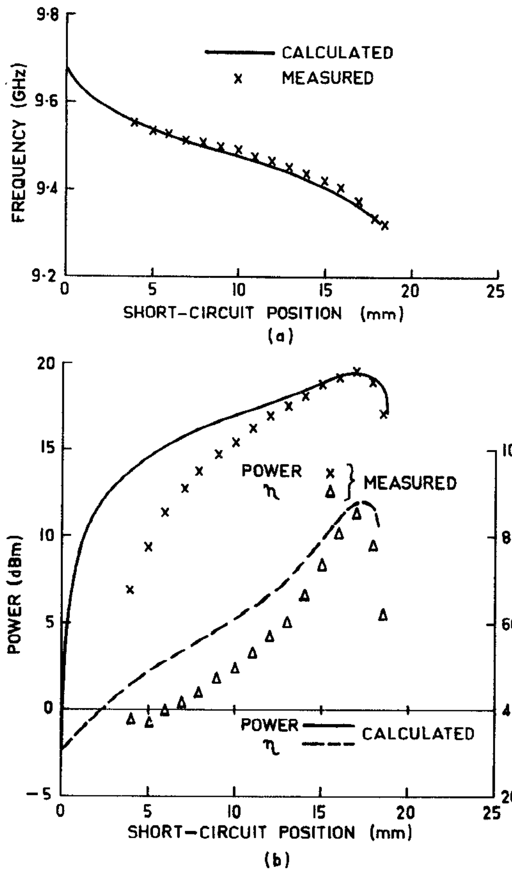

Figure 6: Comparison of calculated and measured (a) frequency of oscillation and (b) power delivered to the waveguide load and the circuit efficiency as a function of the waveguide short-circuit position.

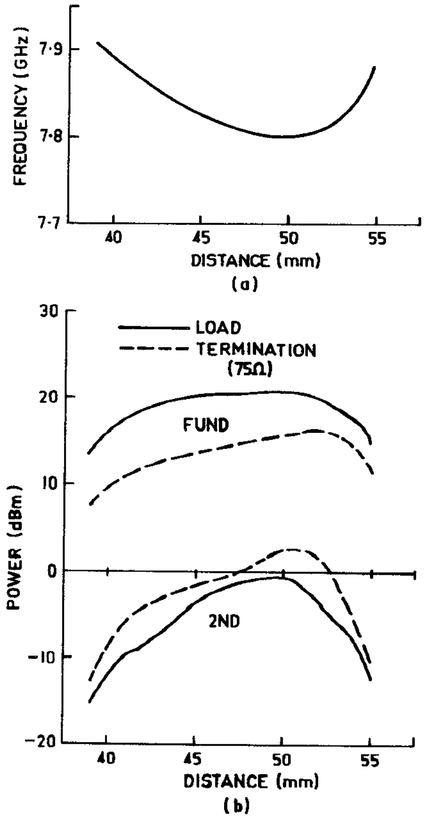

Figure 7: (a) Fundamental frequency and (b) powers delivered to the waveguide load and the coaxial termination at fundamental and second-harmonic frequencies as a function of the coaxial termination position.

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