EXPERIMENTAL INVESTIGATION OF SUBHARMONICALLY PUMPED BALANCED MIXER PERFORMANCE **U-3**

Ross G. Hicks and Peter J. Khan

Electrical Engineering Department, University of Queensland, St. Lucia, Qld, 4067 Australia

ABSTRACT

An experimental study is reported on a subharmonically pumped balanced mixer which permits variation in the degree of imbalance between the two circuit halves. Results show good agreement with theory and indicate the importance of some degree of flexibility in each half of the circuit in order to achieve low conversion loss with these mixers.

1. INTRODUCTION

The subharmonically pumped balanced mixer has attracted considerable interest in recent years for use in low-noise receivers in the millimeter-wave frequency range, since it permits the use of a less expensive local oscillator at around one-half the signal frequency. Additional advantages include the absence of requirements for a diplexer and dc return path, thereby simplifying circuit design. Unfortunately, experimental studies have shown that practical subharmonically pumped mixers often do not provide a performance level (in terms of either conversion loss or noise figure) approaching that predicted by theory [1], [2].

The first major theoretical study in this area was that of Kerr [3], who considered balanced mixers in which both diode circuits were identical. Hicks and Khan developed a novel numerical analysis technique [4] and have applied it [5], [6] to balanced mixers where there is some asymmetry between the two nominally identical diode circuits; this theoretical study indicated that there could be, under certain circumstances, significant performance degratation due to slight imbalance between either the diodes or their associated circuitry.

2. WAVEGUIDE SUBHARMONICALLY PUMPED MIXER LAYOUT

The structure to be analysed consists of two X-band waveguide sections inter-connected through coaxial lines to form a subharmonically pumped mixer (Fig. 1). Each waveguide section contains a post-mounted diode located in a centered position with respect to the broad dimension of the waveguide and placed at the bottom of the waveguide. The input LO and signal power are conbined in a power combiner; this composite signal is then split into two equal composite signals by another power divider and fed into each waveguide through a coax-to-waveguide adapter. A sliding short-circuit of the contacting type is located at the end of each waveguide. The diode post mount is coupled directly into the IF line, which is comprised of a 50-ohm 7-mm airline whose inner conductor is extended to form the post mount. A filter is included in each IF line to confine the LO and signal power to the waveguide. Each IF line is coupled through a double-stub tuner to an output power combiner, the output port of which is connected to a power meter. Bias tees also form part of each IF line, the dc port of which is connected to an ammeter to facilitate measurement of the self-bias current of each diode.

Clearly, a novel feature of this circuit is that the two Schottky-barrier diodes are mounted in separate waveguide diode mounts. This permits independent control of the tuning of the two halves of the balanced mixer by adjustment of the positions of the two sliding short circuits. By this means, it is possible to adjust the degree of imbalance of the two halves of the mixer, for the purpose of experimental investigation. In addition, this circuit also permits a number of LO power settings, ranging from starved to normal operating conditions, to be used.

Frequencies of operation were chosen as follows: signal = 17.2GHz, LO = 8.25GHz, IF = 700MHz. Although the significance and importance of subharmonically pumped mixers is more evident at millimeter-wave frequencies, the study of such a mixer at X-band frequencies is useful since such a structure can serve as a valid low-frequency scaled model for a similar structure at much higher frequencies.

3. DIODE EQUIVALENT CIRCUIT

The devices used were low-barrier matched HP Schottky-barrier mixer diodes, type number HP5082-2714. The equivalent circuit used to represent each Schottky-barrier diode is shown in Fig. 2 with three parasitic elements included, namely: R_s, the series spreading resistance, L_s, the lead-wire inductance and C_p, the package capacitance. These diodes were nominally identical, but each was characterized over the frequency range 6-18 GHz. Slight differences between the two diodes were noted, i.e. 0.125pF and 0.130pF capacitance at zero bias; 6.35Ω and 6.03Ω series resistance; 0.480 mH and 0.440 nH lead inductance.

4. EMBEDDING NETWORK EQUIVALENT CIRCUIT

With the structure of the diode equivalent circuit discussed, a description of the embedding equivalent circuit completes the overall picture of the circuit to be analysed. Only one half of the equivalent circuit of the subharmonically-pumped mixer is shown in Fig. 2; another similar diode with its embedding network is connected on the right-hand side of the diagram.

To assist in the understanding of each element of the embedding circuit, the circuit elements are described here in some detail. Characterization of the circuit was achieved by replacing the coaxial-line-waveguide junction with an equivalent gap structure, following the approach of Eisenhart *et al.* [7] and using their charts; the more accurate approach of Bialkowski and Khan [8] was not available at the time this work was being carried out. This now gives a two-gap structure by using the principle of superposition. This revised structure permits the use of the equivalent circuit of Joshi and Cornick [9] modified by the work done by Hicks and Khan [10]. In the equivalent circuit, Z_4 represents the contribution from all TE_{mo} modes with m>1. Since the circuit under study has a centered post, the TE_{20} mode is uncoupled and has a zero contribution to the equivalent circuit. Z_1 and Z_2 represents contributions from all TE_{mn} and TM_{mn} modes having n>1. In addition Z_3 represents contributions from the same TE and TM higher order modes (n >1) but also includes the contribution of the impedance seen looking into the coaxial line from the coaxial-waveguide interface. Z_5 is the impedance of the TE_{10} modes as determined by the termination provided by the sliding short-circuit. In series with this impedance is the Marcuvitz capacitance, X_6, which represents a phase shift associated with the post thickness. In series with the source of power at each frequency is Z_7 which is equal to the characteristic impedance of the waveguide divided by 2; this division by two is necessary by virtue of the parallel connection of the 2 waveguides through a power divider.

As may be expected, the values of these impedances vary quite markedly with frequency. The direct implication of this statement is that generally the image termination impedance is quite different from that found at the signal frequency, and thus the mixer is clearly not broadband. This may be used to advantage as at maximum *signal* coupling to the diode, the *image* almost certainly will have poor coupling to the diode and therefore the power dissipated at the image frequency will be reduced.

5. RESULTS

The conversion loss for a variety of LO power levels was measured. These values were fed into the mixer-analysis computer program and Fig. 3 shows the agreement. In this diagram, the diode bias currents have been adjusted to be equal by using the sliding short-circuit. Very little variation in short-circuit position (0.025cm) was required to provide equality of bias currents over the range of measurements and the LO power was decreased by 13dB to provide the range of bias currents. As expected, both experimental measurements and theoretical calculations show a decrease in conversion loss with increased bias current. Such a variation is readily accountable by equating increased bias current with stronger pumping, a greater non-linearity of the junction waveforms and thus a consequent improvement in the conversion efficiency. The discrepancies of the order of 2-3 dB bdtween the predicted results and experimentally-measured points are due to circuit losses as well as possible errors in the diode characterization process.

Fig. 4 shows the effect on conversion loss of holding one short-circuit position and the LO power fixed, and adjusting the other short-circuit. In this measurement procedure, the LO power was fixed at 10dBm while one short-circuit position was varied by approximately 1cm. Such a procedure can lead to considerable asymmetry in the embedding-network element adjacent to the mixer diodes. This is shown in Fig. 5 where Z_{11} and Z_{22} of the equivalent two-port of the embedding network are plotted as a function of the short-circuit position, with the calculations being carried on at the frequency $2f_{LO}$. Since for a symmetrical network, Z_{11} should equal Z_{22}, the difference between these two-port parameters demonstrates the degree of imbalance that can be obtained by short circuit adjustment.

As most of the elements of the equivalent circuit represent the embedding network are reactive, such a circuit is resonant at various settings of short-circuit frequency. It is clear from Fig. 4 that the conversion loss is a marked function of short-circuit position, since this factor determines the amount of coupling of LO power and signal power to the diodes. It is obvious from the diagram how slight is the degree of imbalance required to greatly degrade the conversion loss; this figure provides insight into the disappointing results which have been obtained with some circuits in which the two halves of the balanced mixer were ostensibly identical. Again, it appears that in Fig. 4 the discrepancies between the calculated and experimentally measured values are due to losses in the circuit as well as possible errors in the diode characterization process.

Finally, the mixer has proven to give reasonable performance, with the minimum measured conversion loss being 7.9dB.

6. CONCLUSIONS

This is the first reported experimental study of the effect of imbalance between the two halves of a sub-harmonically pumped mixer. The Eisenhart *et al* [7] approach to coaxial line intersections with waveguide was used together with a modified Joshi and Cornick [9], Hicks and Khan [10] diode mount equivalent circuit to give a more accurate circuit model. Reasonably good agreement was found between the numerical computations using this circuit model and the experimentally determined data. The results of this study provide insight into the problems encountered in practical subharmonically-pumped mixers, and show how these problems can be overcome by suitable circuit design. An interesting feature is that dissimilarities between the two diodes can, within limits, be compensated for by appropriate circuit design to obtain performance closely approaching that for the idealized balanced model.

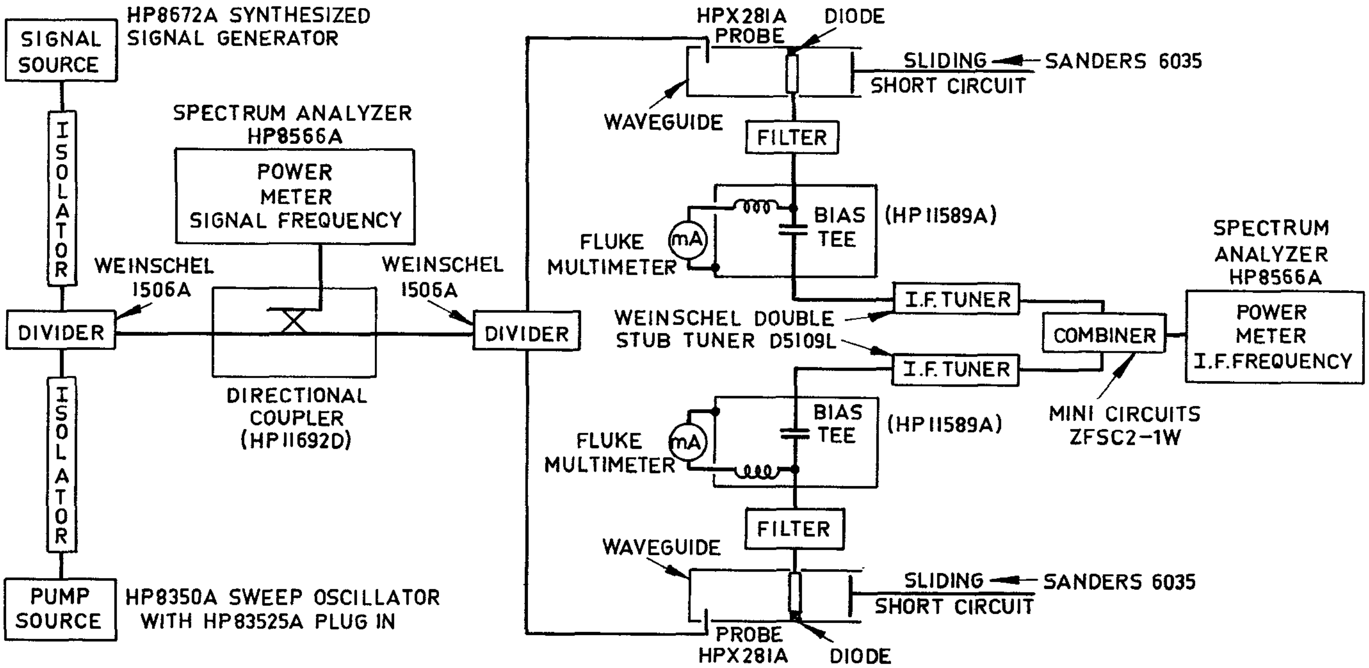

Fig. 1: Experimental circuit for measurement of subharmonically-pumped balanced mixer characteristics.

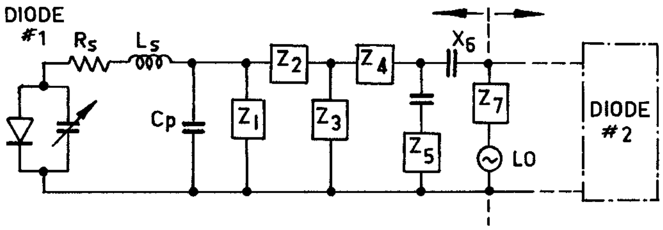

Fig. 2: Equivalent circuit of balanced mixer at the pump frequency; one half of the circuit is shown.

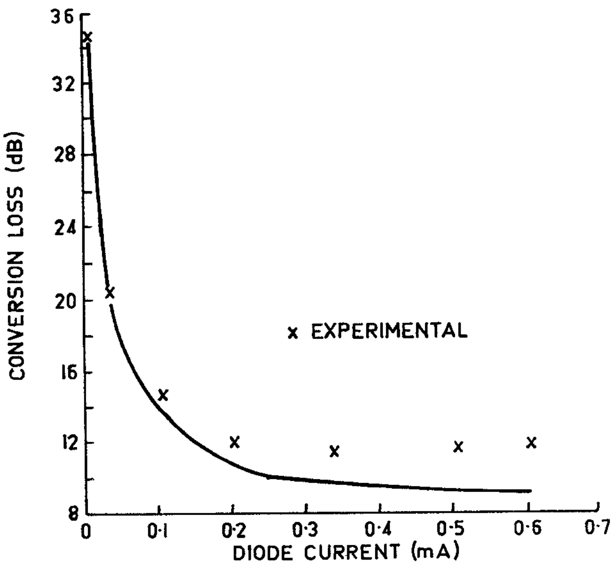

Fig. 3: Mixer conversion loss as a function of local oscillator power, represented by diode current.

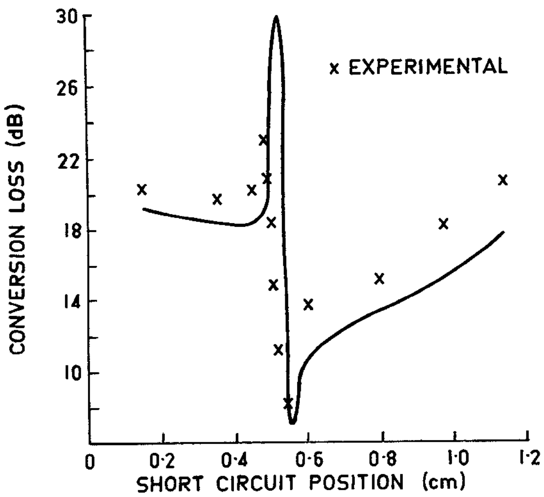

Fig. 4: Variation in mixer conversion loss with imbalance between the two halves of the mixer through change in the position of one waveguide short circuit while the position of the short circuit is held constant on the other half of the circuit.

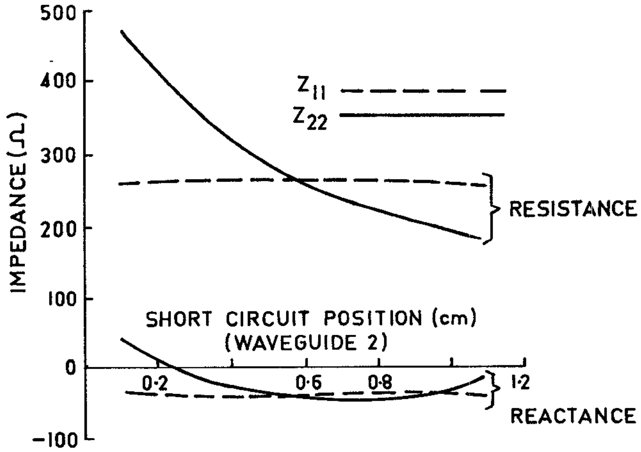

Fig. 5: Impedance parameters Z_{11} and Z_{22} of the two-port network between the two diodes in the balanced mixer.

7. ACKNOWLEDGEMENTS

This work was supported by United States A.R.O., Telecom Australia and the Australian Research Grants Committee.

8. REFERENCES

[1] A.R. Kerr, private communication.

[2] A.G. Cardiasmenos, private communication.

[3] A.R. Kerr, "Noise and loss in balanced and subharmonically-pumped mixers: Parts 1 and 11: Theory and Application", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-27, pp. 938-950, Dec. 1979.

[4] R.G. Hicks and P.J. Khan, "Numerical analysis of nonlinear solid-state device excitation in microwave circuits", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 251-259, March 1982.

[5] R.G. Hicks and P.J. Khan, "Analysis of balanced subharmonically-pumped mixers with unsymmetrical diodes", *IEEE MTT-S International Microwave Symposium*, Los Angeles, pp. 457-459, June 1981.

[6] R.G. Hicks and P.J. Khan, "Numerical analysis of subharmonic mixers using accurate and approximate models", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 2113-2120, Dec. 1982.

[7] R.L. Eisenhart, P.T. Greiling, L.K. Roberts, and R.S. Robertson, "A useful equivalence for a coaxial-waveguide junction", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 172-174, March 1978.

[8] M.E. Bialkowski and P.J. Khan "Modal analysis of a coaxial-line waveguide junction", *IEEE MTT-S International Microwave Symposium*, Boston, June 1983.

[9] J.S. Joshi and J.A.F. Cornick, "Analysis of a waveguide mounting configuration for electronically tuned transferred electron device oscillators and its circuit applications:, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 573-584, Sept. 1976.

[10] R.G. Hicks and P.J. Khan, "Improved waveguide diode mount circuit model using post equivalence factor analysis", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1914-1920, Nov. 1982.