ANALYSIS OF BALANCED SUBHARMONICALLY PUMPED MIXERS WITH UNSYMMETRICAL DIODES

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ABSTRACT

A numerical analysis technique is applied to subharmonically pumped balanced mixer circuits where the two diodes differ from each other. Results indicate that a slight imbalance between the diodes has a pronounced effect on mixer performance.

Introduction

A cornerstone in the development of mixer theory has been the application of nonlinear analysis techniques to the determination of mixer performance, using a variety of numerical methods[1-5]. Using the Gwarek approach[2], Held and Kerr[6] have carried out a comprehensive study of the single-diode mixer circuit.

With the increasing interest in balanced mixers particularly at millimeter wave frequencies, numerical methods have been directed towards analysis of such mixers, particularly under sub-harmonic pumping conditions. Kerr[7] has presented a detailed analysis of these mixers for the case where the two diodes are assumed to be identical.

In practice, it has not been possible to readily reproduce the theoretical results under experimental conditions, although some good experimental results have been reported[8-11]. Experimentalists have found that both slight changes in diode mounting and replacement of diodes have had a pronounced effect on performance.

This paper reports a study carried out in response to the pressing need for a nonlinear analysis of the balanced subharmonically-pumped mixer in which the two diodes differ from each other, either in device characteristics or in mounting configurations. The approach of Kerr[7] is not readily extended to the unsymmetrical-diode case, since it rests upon use of circuit symmetry to reduce the multi-diode circuit to an equivalent single-diode circuit which may be readily analysed by the techniques available in the literature.

An extension of Kerr's multiple reflection algorithm to the general multidiode situation has been reported recently by Faber and Gwarek[12]. This method has not been used here as performance figures[5] based on the single diode counterparts of the two diode analysis methods available indicate the method described here has significant advantages of efficiency over the Faber and Gwarek approach.

Nonlinear Analysis Approach

The approach is based upon an extension of a single-diode nonlinear analysis technique published by the present authors[5].

The circuit is subdivided into three sections, comprising two nonlinear one-ports and a connecting linear two-port containing the embedding network within which the pump source is located (Fig. 1).

To commence the algorithm, sinusoidal waveforms are assumed for $I_1(t)$ and $V_2(t)$. The periodic voltage response $V_1(t)$ that diode 1 produces in response to the input $I_1(t)$ may be determined by successively integrating (using the classical Runge-Kutta algorithm) the nonlinear diode equation until transients decay, viz:

$$\frac{dV_1(t)}{dt} = \frac{I_1(t) - i_1[\exp(qV_1(t)/\eta kT) - 1]}{C_1(V_1(t))}$$

where the capacitance term is calculated using the normal varactor equation, viz:

$$C_1(V_1(t)) = C_{01}(1 - V_1(t)/\phi)^{-\gamma} \quad \text{and}$$

i_1 is the diode 1 saturation current.

The current, $I_2(t)$, sourced by the linear network may be calculated using the known Z parameters of the two-port as follows:

$$I_2(\omega) = \left(\frac{V_2(\omega) - Z_{21}I_1(\omega) - V_2^{oc}(\omega)}{-Z_{22}}\right)$$

where $V_2^{oc}(\omega)$ is the open circuit voltage at interface 2. The above linear network calculations are most efficiently done in the frequency domain. A Fast Fourier Transform is used to convert between the frequency and time domain.

With $I_2(t)$ available, a revised voltage $\overset{*}{V}_2(t)$ at interface 2, may be calculated as for diode 1, viz:

$$\frac{d\overset{*}{V}_2(t)}{dt} = \frac{I_2(t) - i_2[\exp(q\overset{*}{V}_2(t)/\eta kT) - 1]}{C_2(\overset{*}{V}_2(t))}$$

where C_2 and i_2 are similarly defined to those for diode 1.

Similarly, $\overset{*}{I}_1(\omega)$ may be calculated in the frequency domain:

$$\overset{*}{I}_1(\omega) = \left(\frac{V_1(\omega) - Z_{12}I_2(\omega) - V_1^{oc}(\omega)}{-Z_{11}}\right)$$

Two convergence parameters, p_1 and p_2, one for each diode are introduced. Determination of their values is based on criteria derived from a detailed convergence analysis. They are used to provide the next iterate of $I_1(t)$ and $V_2(t)$, namely $I_1^{\#}(t)$ and $V_2^{\#}(t)$, viz:

$$I_1^{\#}(t) = p_1\overset{*}{I}_1(t) + (1-p_1)I_1(t)$$

$$V_2^{\#}(t) = p_2\overset{*}{V}_2(t) + (1-p_2)V_2(t)$$

One iteration of the loop has now been completed, giving revised values of the periodic waveforms $I_1(t)$ and $V_2(t)$. Iterations proceed until stationary solutions are achieved for these waveforms.

The resulting computer program performed satisfactorily.

Small Signal and Noise Analysis

The method of analysis is that recently published by Kerr[7]. This enables the conversion loss, mixer

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output impedance and the mixer input temperature to be calculated.

Application of the Analysis

Studies were carried out on the balanced mixer circuit examined by Kerr, given as example 1 in his paper[7]. This circuit presents zero coupling at frequencies above the signal frequency. At other frequencies, the load seen by the diodes is 50Ω. In the unperturbed (or equal diode case), the diode parameters used were as follows: $R_s = 10\Omega$, $C_o = 7fF$, $L_s = .4nH$, $\eta = 1.12$, $\phi = .95V$, $\gamma = 0.5$, $i_o = 8 \times 10^{-17}A$. The signal, pump and I.F. are at 103, 50 and 3 GHz. Subsequently both the lead inductance and zero-bias capacitance values of diode 2 were allowed to vary, yielding the effects shown in Figs. 2 and 3. In all cases, the L.O. power was adjusted to give a rectified current of 2mA in diode 1. When the capacitance was varied, the series resistance of diode 2 was modified such that the C_oR_s product remained constant. In both Figs. 2 and 3, the rectified current of diode 2 is plotted.

Discussion

As in the identical diode situation analysed by Kerr[7], variations in the lead inductance and zero bias capacitance in one diode have significant effects on the overall performance of the mixer. A resonance between the lead inductance and capacitance of diode 2 is responsible for the poor conversion loss, with the resonant frequency being in the vicinity of the signal frequency. An examination of the current waveforms (Fig. 4) illustrates this point further. The resonant conditions of diode 2 are evident in the second negative current excursion.

Compensation for the poor conversion losses may be achieved by addition of a separate d.c. bias supply for diode 2, as shown in Fig. 5. In this case, the bias is adjusted until the rectified currents of both diodes (2mA) are equal. The resulting conversion loss diagram shows the absence of the resonant peak. The shift in the bias point on the varactor capacitance curve to a larger value of capacitance tends to offset the fall in the inductance and the resonant frequency is kept below the signal frequency.

Alternatively, when the diodes are mounted in waveguide, compensation for the variation in inductance and capacitance may be obtained readily by adjustment of the gap height. The coupled high order TE and TM modes provide a variable reactive shunt across the gap terminals[13]. Adjustment of the gap height gives a range of compensatory reactance values for use in adjusting the diode current values for equality.

An interesting feature in both Figs. 2 and 3 is the sensitivity of the rectified current in diode 2 to the diode parameter imbalance. This has been experimentally reported in the literature[14]. The sharp variation in current is due to the proximity of the lead inductance - junction capacitance resonance to the fundamental pump frequency.

Acknowledgements

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References

1. D.A. Fleri and L.D. Cohen, "Nonlinear analysis of the Schottky-barrier mixer diode", IEEE Trans. Micro. Theory Tech., Vol. MTT-21, No. 1, January 1973, pp. 39-43.
2. W.K. Gwarek, "Nonlinear analysis of microwave mixers", M.S. Thesis, Mass. Inst. Technol., Cambridge, Mass., Sept. 1974.
3. S. Egami, "Nonlinear, linear analysis and computer-aided design of resistive mixer", IEEE Trans. Micro. Theory Tech., Vol. MTT-22, No. 3, March 1974, pp. 270-275.
4. A.R. Kerr, "A technique for determining the local oscillator waveforms in a microwave mixer", IEEE Trans. Micro. Theory Tech., Vol. MTT-23, No. 10, Oct. 1975, pp. 828-831.
5. R.G. Hicks and P.J. Khan, "Numerical technique for determining pumped nonlinear device waveforms", Electronics Letters, Vol. 16, No. 10, 8 May 1980, pp. 375-376.
6. D.N. Held and A.R. Kerr, "Conversion loss and noise of microwave and millimeter-wave mixers: Parts 1 and 2: Theory and experiment", IEEE Trans. Micro. Theory. Tech., Vol. MTT-26, No. 2, February 1978, pp. 49-61.
7. A.R. Kerr, "Noise and loss in balanced and subharmonically pumped mixers: parts I and II: Theory and application", IEEE Trans. Micro. Theory Tech., Vol. MTT-27, No. 12, Dec. 1976, pp. 938-950.
8. T.F. McMaster, M.V. Schneider and W.W. Snell, "Millimeter-wave receivers with subharmonic pump", IEEE Trans. Micro. Theory Tech., Vol. MTT-24, No. 12, December 1976, pp. 948-952.
9. R.E. Forsythe, V.T. Brady and G.T. Wrixon, "Development of a 183 GHz subharmonic mixer", IEEE MTT-S International Microwave Symposium, Florida, April-May 1979, pp. 20-21.
10. E.R. Carlson, M.V. Schneider and T.F. McMaster, "Subharmonically pumped millimeter-wave mixers", IEEE Trans. Micro. Theory Tech., Vol. MTT-26, No. 10, October 1978, pp. 706-715.
11. M.V. Schneider and W.W. Snell, "Harmonically pumped stripline down-converter", IEEE Trans. Micro. Theory Tech., Vol. MTT-23, No. 3, March 1975, pp. 271-275.
12. M.T. Faber and W.K. Gwarek, "Nonlinear-linear analysis of microwave mixer with any number of diodes", IEEE Trans. Micro. Theory Tech., Vol. MTT-28, No. 11, November 1980, pp. 1174-1181.
13. R.L. Eisenhart, "Understanding the waveguide diode mount", IEEE MTT-S International Microwave Symposium, Arlington Heights, May 1972, pp. 154-156.
14. M. Cohn, J.E. Degenford and B.A. Newman, "Harmonic mixing with an antiparallel diode pair", IEEE Trans. Micro. Theory Tech., Vol. MTT-23, No. 8, August 1975, pp. 667-673.

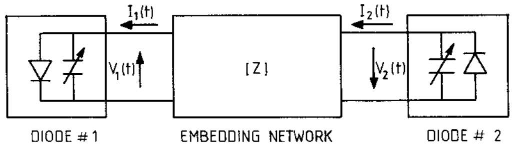

Figure 1: Subdivision of the Subharmonic Mixer Circuit

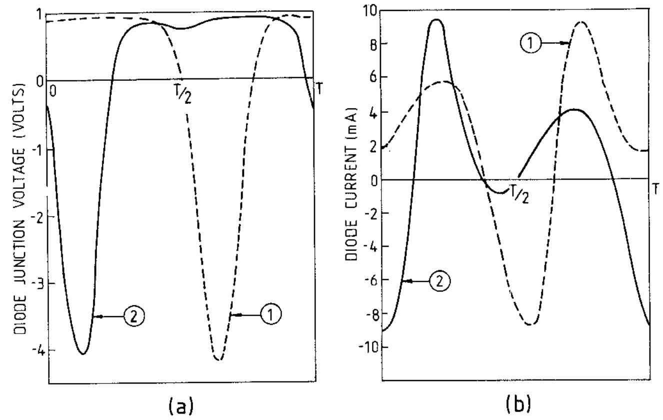

Figure 4: The Voltage and Current Waveforms of Both Diodes. Diode 2 Parameters are L_S = .325nH, C_{02} = 7.0fF.

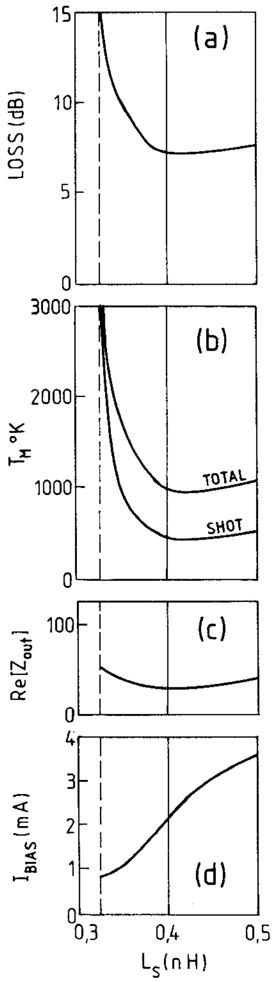

Figure 2: Mixer Conversion Properties and Diode 2 Rectified Current versus Inductance Variation.

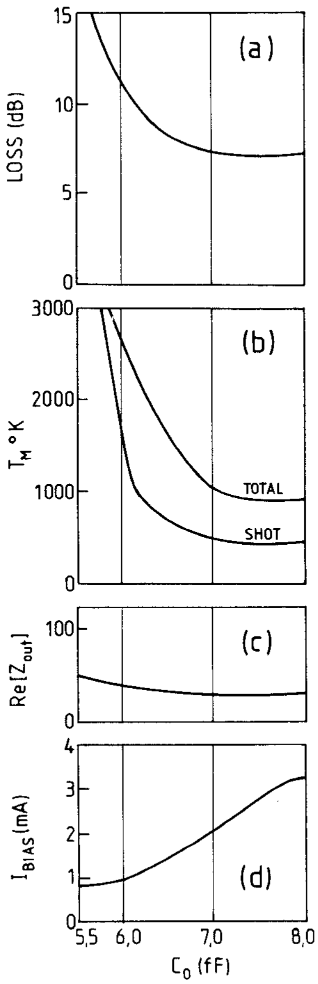

Figure 3: Mixer Conversion Properties and Diode 2 Rectified Current versus Capacitance Variation.

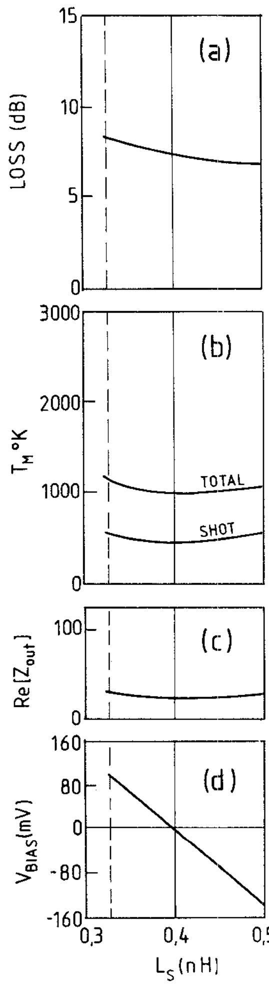

Figure 5: Mixer Conversion Properties and Diode 2 Bias Voltage versus Inductance Variation.