AN APPROACH TO OPTIMAL MIXER DESIGN AT MILLIMETER AND SUBMILLIMETER WAVELENGTHS

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ABSTRACT

The mixer performance analysis procedures reported by the author in (1,2) have been incorporated into an optimal synthesis technique. The technique has been experimentally verified at 115 GHz and should produce good results at frequencies in excess of 300 GHz.

Introduction

The mixer analysis procedures previously reported by this author (1,2) have substantially improved the understanding of mixer performance in the upper reaches of the millimeter-wave region. The logical extension of this work leads to an approach toward the optimal synthesis of mixers in this part of the spectrum. Thus, the computer analysis programs written for the previous study have been combined with standard minimization techniques (3), to yield a program that minimizes the system noise temperature (T_S), with respect to the diode embedding impedances. The result of the minimization is a set of optimum embedding impedances which the designer may use as goals when designing a mixer mount.

Technique

Block diagrams of the analysis technique, and the subsequent optimization technique are illustrated in Figures 1 and 2 respectively. Both techniques presume a detailed knowledge of the equivalent circuit of the diode at the frequency of interest. The analysis technique also requires knowledge of the embedding impedances at the harmonics of the local oscillator, whereas the optimization technique minimizes the system noise temperature with respect to these impedances and produces a list of the optimum embedding impedances as an output.

The optimization routines were typically written to minimize the single sideband system noise temperature ($T_S = T_M + L\,T_{Amp}$, where T_M is the mixer noise temperature, L is the conversion loss, and T_{Amp} is the noise temperature of the intermediate amplifier chain) with respect to the real and imaginary part of the embedding impedance at the local oscillator (LO) frequency. For simplicity, the impedances at the LO frequency and the signal and image frequencies were assumed to be identical. Simultaneous optimization with respect to the embedding impedances at the LO and its harmonics was also investigated yielding very similar results, but requiring substantial amounts of computer time. The observed insensitivity to second and higher order harmonic effects is probably due to the diode's relatively poor conversion efficiency at these higher frequencies. For these reasons optimization was generally carried out only at the local oscillator frequency.

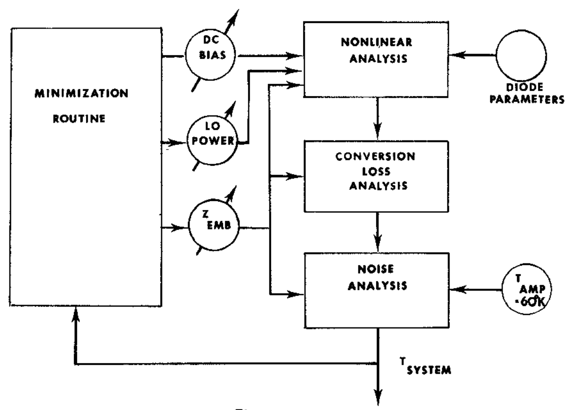

Figure 2

Figure 2 - Diagram of optimization technique. The output of the Technique is a set of optimum embedding impednaces.

The optimization technique was exercised for a GaAs diode operating at 115 GHz yielding the results depicted in Figure 3. The several points on the Smith Chart reflect the results of slightly different assumptions regarding the frequency dependence of the skin effect-caused series resistance (see Reference 2 for a complete discussion) and different bias points. However, the points cluster around an embedding impedance of 55 + j 75 ohms, which leads to a predicted single sideband mixer noise temperature of 470°K ± 50°K, and a single sideband conversion loss of 4.9 db ± 0.1 db.

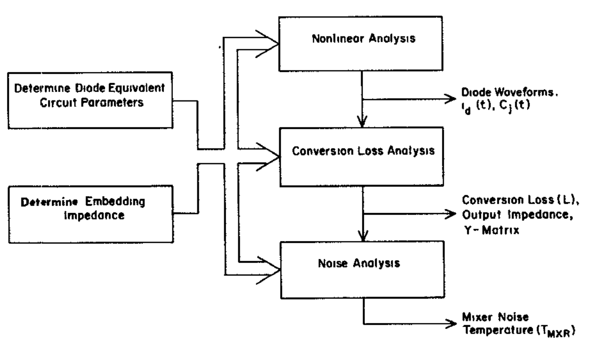

Figure 1

Figure 1 - Diagram of Mixer Analysis Technique

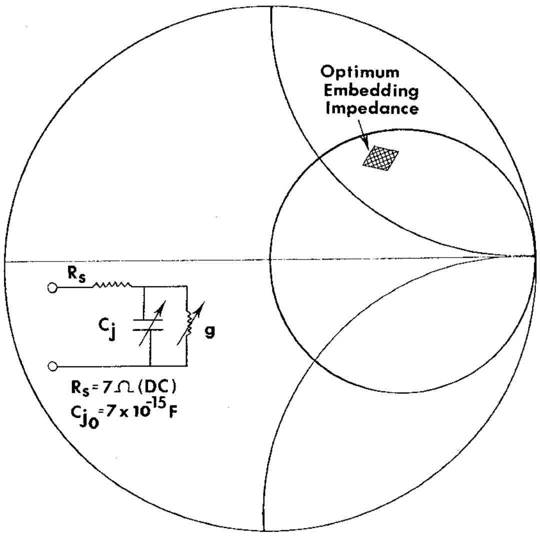

Figure 3

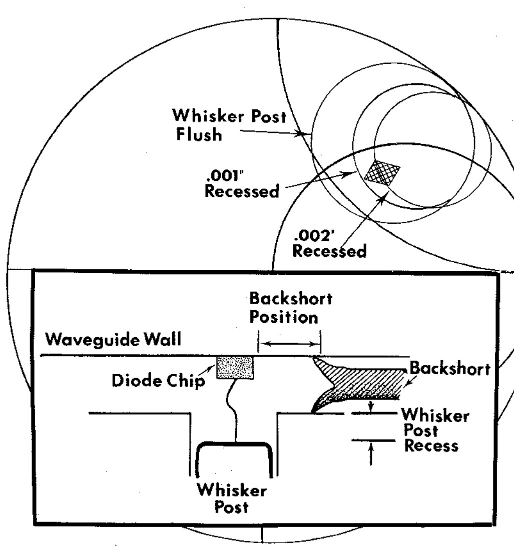

Figure 4

Figure 3 - Optimum LO-Frequency Embedding impedance range for diode mixer at 115 GHz

Experimental Results

In an effort to synthesize a mixer mount geometry which would provide the appropriate optimum embedding impedance to the diode, an L-band model (2,4) of a widely used 115 GHz mixer (5) was employed; a network analyzer measuring the impedance in the plane of the diode. The embedding impedance "seen" by the diode was measured as a function of the backshort position, however, as indicated in Figure 4, it was clearly necessary to modify the mount to synthesize the appropriate impedance. In particular it was found necessary to add some inductance; thus the length of the contacting whisker was increased, forcing the whisker post to recess into the waveguide wall.

Experimental validation of the optimum design point, using a functional 115 GHz mixer, involved a laboreous effort of precisely contacting numerous diodes on a chip using different whisker lengths and consequently different whisker post recesses into the waveguide wall. The procedure did not allow for the recontacting of the identical diode in the matrix every time. However, the series resistance and junction capacitance of each diode was monitored and the junction was inspected under an electron microscope to preclude any poor mechanical contacts.

A plot of the measured conversion loss (L) and mixer noise temperature (T_M) as a function of the whisker post position is illustrated in Figure 5, where it is obvious that a strong minimum occurs when the whisker post is recessed 1-2 mils into the guide wall as predicted by the theory (Figure 3) and the L-band mixer model (Figure 4). Further the measured performance of the mixer in this optimized mount is entirely consistent with the results predicted by the optimization technique.

A mixer similar to the one just described is presently being used on the Columbia-GISS radio telescope in New York (6) and is believed to represent the state of the art 115 GHz in room temperature mixers.

Figure 4 - Synthesis Experiment on L-Band Mixer Model. The results indicate that the optimum embedding impedance is achieved by recessing the whisker post 1-2 mils into the waveguide wall.

Predicted Optimal Mixer Performance: 100-600 GHz

The optimal design technique was employed over the frequency of 100 GHz to 600 GHz to predict the performance limitations of GaAs Mixers at these frequencies. The results are illustrated in Figure 6, and indicate that single sideband system temperatures under 2000°K should be realizable in principle up to the limit of the millimeter-wave spectrum. However, a word of caution is required here. The system temperatures quoted apply to the mixer diode only and do not include additional sources of noise due to passive losses or noise contributions due to local oscillator noise. In addition, the extreme requirements on mechanical tolerance evidenced in Figure 5 at 115 GHz are clearly worse at the higher frequencies. Further, the results for frequencies in excess of 300 GHz are somewhat suspect since the equivalent circuit of the diode (Figure 3) is probably no longer strictly valid at these frequencies due to carrier transit time effects.

REFERENCES

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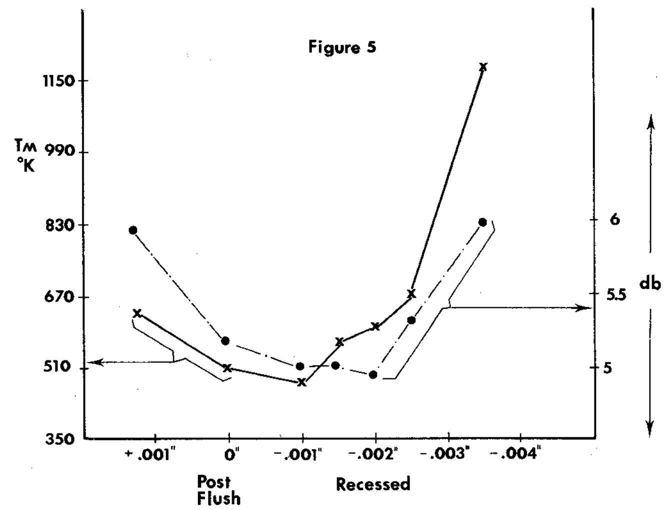

Figure 5 - Experimental Results Utilizing a Functional 115 GHz Mixer. The experiment indicated that the optimum whisker post position is between 1 and 2 Mils recessed, confirming the theoretical analysis.

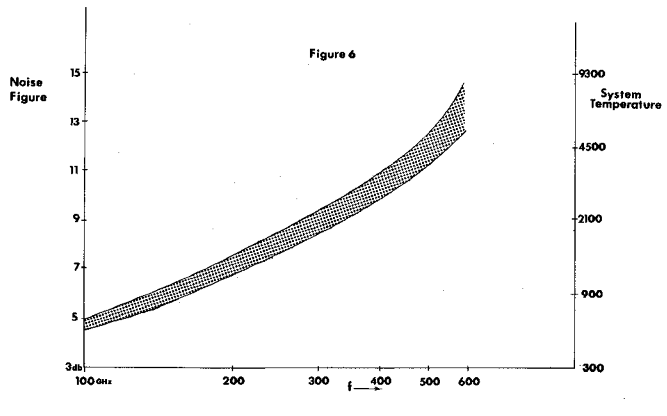

Figure 6 - Predicted System Temperatures of Optimal Mixers as a function of frequency. The IF amplifier is assumed to be parametric and have an input temperature of 60°K. The optimal 115 GHz mixer described in the text lies between the theoretical limits.

Acknowledgement

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