A SIMPLE MICROWAVE FREQUENCY CONVERTER

Hong Keun Lee and Edmar Camargo
Laboratório de Microeletrônica, Universidade de São Paulo
Cx P 8174 - 01051 São Paulo, BRAZIL

ABSTRACT

A microwave frequency converter composed of a harmonic oscillator directly connected to a Schottky diode mixer has been developed. The design tecniques are discussed and applied to the realization of a frequency converter for operating from 11 GHz to 1 GHz. The practical results of a prototype constructed on alumina substrate are as follows: conversion loss of 8 dB, noise figure of 8 dB, and a 1 dB conversion compression level of 0 dBm at the input.

INTRODUCTION

In microwave receivers, the frequency converter is an important system block, and its design has been frequently addressed with excellent electrical perfomance in recent published papers. For instance, a paper[1] on a frequency converter for DBS application, presented 52 dB conversion gain from 12 GHz to 1 Ghz and a noise figure of 2.1 dB. Another, directed to Communication Satellites[2] presented 10 dB conversion gain and 8 dB noise figure for approximately the same frequency bands. The approach followed in these publications is to employ a conventional oscillator coupled to a single gate MESFET mixer or to Gilbert cells mixers, which are rather complex.

The objective of this paper is to present a simple frequency converter composed of a harmonic oscillator coupled to a Schottky diode mixer, that trades off electrical performance with circuit simplicity, a desirable characteristic for monolithic integration. The design of harmonic oscillators and Schottky diode mixers has been published elsewhere[3,4]. However, there seems to be no published information of a harmonic oscillator directly connected to a diode mixer, which is the subject of this paper. The design approach is discussed along with the application of non-linear simulations to obtain the design criteria for each component as well as for the coupling of two non-linear components. The application envisaged is for DBS, operating at an input frequency of 11 GHz and an IF of 1 GHz. The technique is demonstrated with a converter built on thin film technology on alumina substrate.

THE DESIGN APPROACH

The approach followed in this paper to design a frequency converter started by choosing a harmonic oscillator. In this configuration, the oscillator presents the advantage of being more independent of load impedance compared to conventional oscillators. Thus, it can be connected to a Schottky diode mixer without generating unwanted signals. The block diagram of the circuit is shown in figure 1, which employs two dielectric resonators, one to stabilize the oscillator and another to improve the LO to RF isolation. Except for the dielectric resonators the circuit is adequate for monolithic integration.

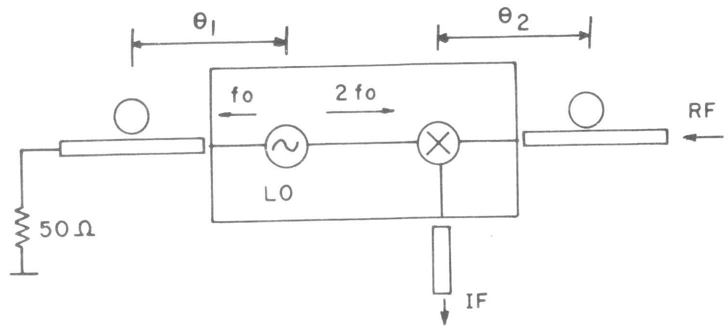

Fig 1 - Frequency Converter Block Diagram.

A. HARMONIC OSCILLATOR DESIGN

The design approach is similar to a previous published paper[3], where the large signal transconductance obtained from the simulation of a low frequency multiplier is used in the linearization of a MESFET model. The S-parameters of this model at the fundamental frequency were then employed in the determination of the optimum source termination which gives $S_{11}' > 1$, when the drain is shorted to ground by an open stub 90^o long. The oscillator topology employed in this paper is shown in figure 2 and the impedances connected to the device at the fundamental and second harmonic are listed in table I.

Fundamental Frequency	Second Harmonic
$Z_D(wo) = 0$	$Z_D(2wo) = R_{D2}$
$Z_S(wo) = -jX_S$	$Z_S(2wo) = 0$
$Z_G(w0) = R_G + jX_G$	$Z_G(2wo) = 50$ ohms

Table I. Impedances at the fundamental and second harmonic

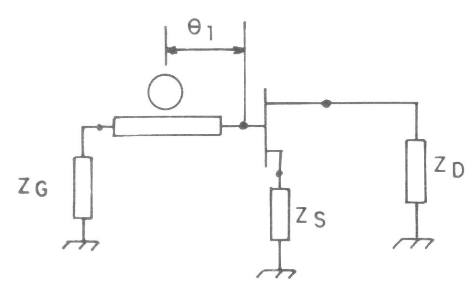

Fig 2 - Harmonic oscillator topology.

The source termination was implemented by a 40 ohms open stub 90^0 long at the second harmonic, for reasons of stability and optimum second harmonic power transfer to the load. The gate impedance takes into account losses in the resonator, and establishes the oscillator fundamental frequency.

The device type ATF 26100 by Avantek, possesing 0.25 um gate length, was employed in this design. The gate biasing was selected for trading off harmonic generation and oscillation condition. A positive return loss of 3.5 dB was obtained for a wide range of source capacitive termination. Employing PSPICE it was found that the oscillator equivalent circuit at the second harmonic is represented by a current source with an internal RC parallel impedance. Figure 3 shows the simulated second harmonic power as a function of load impedance when the output capacitance is tuned. It is observed that any resistance between 60 to 130 ohms, will guarantee an output power greater than 13 dBm.

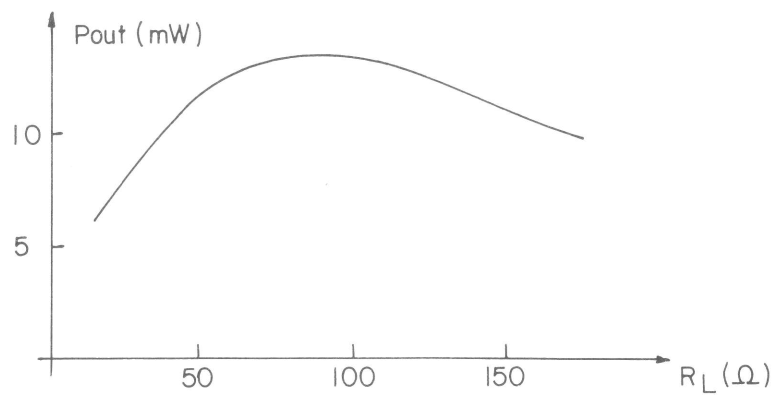

Fig 3 - Second harmonic output power x load resistance.

B. SINGLE DIODE SCHOTTKY MIXER DESIGN

The diagram of a basic diode mixer is shown in figure 4a. A 3x3 conversion matrix was extracted from this simple circuit using PSPICE to obtain the resulting current, when generators 1 and 2 are applied simultaneously to the diode. Generator 1 represents the local oscillator and generator 2 represents either the RF, the Image or the IF signals. The non-linear equivalent circuit of the Schottky diode is shown in figure 4b.

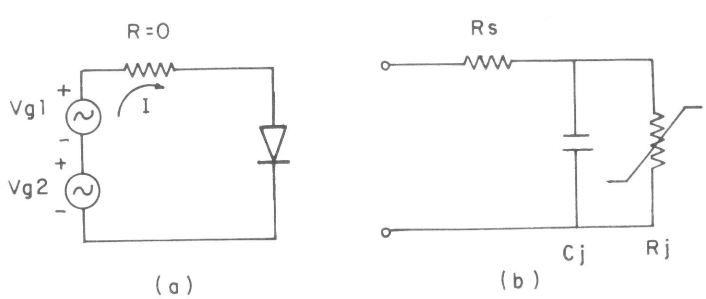

Fig 4 - Basic diode mixer and equivalent circuit.

A PROTOTYPE EXAMPLE

The application of the described approaches is demonstrated through the design of a prototype for converting 11 GHz to 1 GHz. For the sakeness of circuit simplicity the RF signal is not isolated from the LO output impedance. Thus, part of the RF signal will be wasted in the oscillator impedance, found by simulation to be equal to 100 ohms. This will increase the conversion loss from 5.5 dB to 7 dB, which still is an acceptable result if one considers that a low noise amplifier precedes the converter. The experimental prototype was constructed on 0.4 mm thick alumina substrate, employing microstrip transmission lines. The chip transistor and the beam-lead diode were connected directly to the golden pads using conventional bonding techniques. The photo of figure 7 displays the experimental prototype used in the measurements.

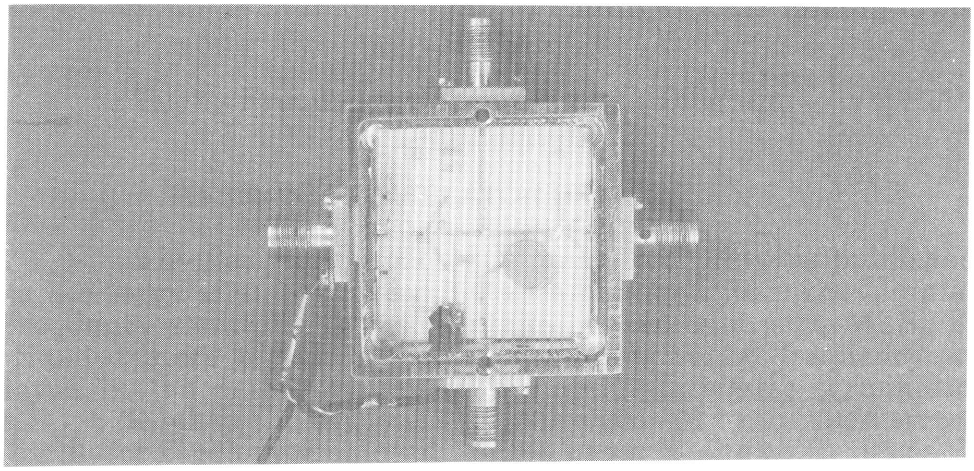

Fig 7 - Photo of the thin film frequency converter.

It is observed that a series transmission line had to be inserted between both components due to lay-out constraints. This line also has a transforming function and was designed to improve the circuit performance. Employing a 50 ohms, 60^{o} long transmission line, the crossing point moves to point P on the oscillator plane and to point Q on the diode plane, resulting in higher voltage at the diode. This will reduce the intermodulation products at the cost of 0.5 dB increase in the conversion loss. The lay-out also provides means for testing each component independently.

Initially the negative resistance of the oscillator at the fundamental frequency of 6 GHz was checked in the network analyzer. A difference of less than .5 dB was observed in the measured and predicted input return loss. Coupling the resonator to the gate terminal, an output power of + 7 dBm was obtained at the second harmonic. The mixer, driven with a + 7 dBm external local oscillator, showed a conversion loss of 9 dB. After these preliminary tests, the mixer was connected to the local oscillator.

The obtained insertion loss and the noise figure are shown in the plot of figure 8. The frequency response is flat over 500 MHz bandwidth and the noise figure decreases from 9 dB at the low frequencies to 7.5 dB at high frequencies. Other parameters of interest are the LO-RF isolation, 19 dB, the RF-LO isolation, 11 dB and the 1 dB conversion compression level of 0 dBm referenced at the input. The measured VSWR at RF band is in the order of 2.5.

The conversion matrix was calculated for the Silicon beam-lead diode type HP 5082-2229 by Hewllet-Packard. Assuming the same termination for the RF and Image signals, the calculated conversion loss, Lc, as a function of local oscillator peak voltage is depicted in figure 5.

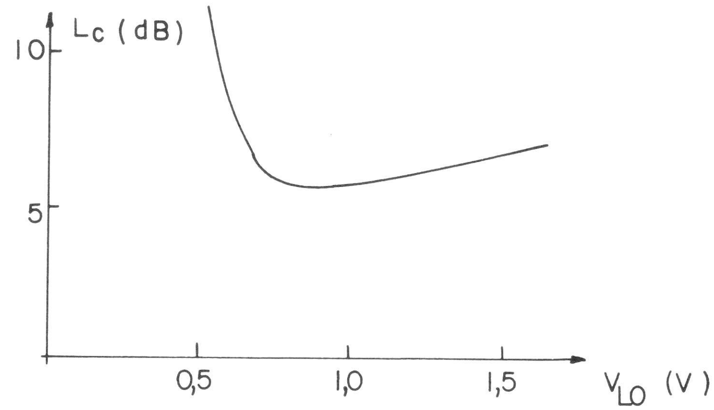

Fig 5 - Conversion loss as a function of LO voltage.

OSCILLATOR-MIXER CONNECTION

The problem of determining the voltage and current at the connection of both non-linear circuits can be reduced to the determination of the common voltage that satisfies the resulting current for each non-linear component at the specified frequency. The general analytic solution to this problem is quite complex. Fortunately a graphical solution can be applied, if the oscillator output impedance and the diode impedance are assumed resistive. Thus, providing a means for tuning the capacitive reactances, one can plot the oscillator load impedance and the diode large signal input impedance as a function of the common voltage. The point of intersection depicted in figure 6 is the solution to the problem.

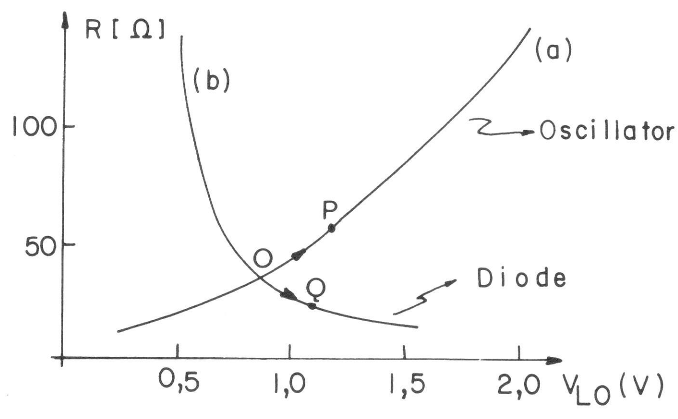

Fig 6 - Determination of the connection parameters.

The obtained operating point for this connection is 0.85 volts and 35 ohms, which corresponds to an oscillator output power of + 9 dBm and to a conversion loss of 5.5 dB.

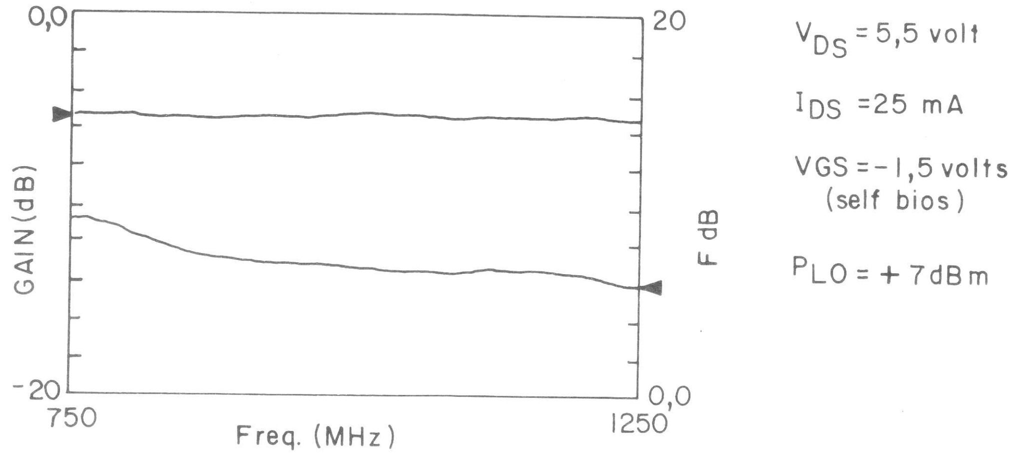

Fig 8 - Measured conversion loss and noise figure.

CONCLUSIONS

This paper presented an approach for the design of a simple frequency converter, comprising a GaAs MESFET harmonic oscillator and a single Silicon Schottky diode mixer. The results obtained with a simple experimental prototype were very close to those predicted by non-linear analysis using PSPICE. The frequency converter showed stable operation, a flat conversion loss of 8 dB within more than 500 MHz and a maximum noise figure of 9 dB with only 125 mW of DC power consumption. These results confirms the effectiveness of the design method and its adequacy to monolithic design.

ACKNOWLEDGEMENTS

This work has been carried out under the sponsorship of FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo.

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