4 TO 40 GHZ EVEN HARMONIC SCHOTTKY MIXER

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ABSTRACT

Second harmonic mixing from 4 to 40 GHz with a 2 to 20 GHz LO has been obtained using an eight diode antiparallel bridge in a balanced microstrip circuit. The development and testing of this mixer, which includes a lumped element diplexer, was expedited by a 10X scale model at 4 GHz.

INTRODUCTION

This paper reports on the development and implementation of a broadband, reflection type, second harmonic mixer, operating over a 4 to 40 GHz signal frequency (RF) band, and a 2 to 20 GHz local oscillator (LO) band. The mixer employs an eight diode antiparallel bridge in a balanced microstrip circuit to simultaneously achieve low conversion loss and high LO to RF isolation.

Second harmonic mixing using two antiparallel Schottky diodes was first investigated by Cohn (1) and Schneider (2). These concepts were extended by Neuf (3) to include four pairs of antiparallel diodes in a bridge circuit, allowing one to introduce LO energy with multioctave RF isolation from 2 to 18 GHz. The present 4 to 40 GHz unit has significantly wider bandwidth, and is particularly useful for EW receiver applications where both microwave and millimeter wave coverage is needed.

PRINCIPLE OF OPERATION

Single pair or multiple pair diode harmonic mixers achieve mixing action by reflecting RF energy from periodically changing diode impedances. Alternate diodes become forward biased during the positive and negative cycle of the LO, presenting an "on" reflection coefficient of -1. During a short transition period when there is insufficient LO voltage to turn the diodes "on", an "off" reflection coefficient of +1 is presented. Hence, "on" and "off" ideal RF reflection coefficients of ±1 occur twice for each LO cycle. The phase difference of 180° between states must be maintained across the band of each of the two different ports of the diode package. This requirement is easily satisfied at lower frequencies, but becomes exceedingly difficult to meet as frequency increases, due to parasitic inductance associated with the diode configuration. To quantify this effect, frequency scaling techniques are employed to establish short and open circuit reference planes at each port of a scaled diode package. "On" and "off" conditions, which approximate physical diode states, are alternately measured at 4 GHz, and the phase difference ascertained. The results determine which of the two ports will serve as the higher frequency RF port. The frequency scaling results correlate with measured performance at 40 GHz.

A disadvantage of reflection mixers is that all mixing products appear across the diode bridge. This necessitates the use of a diplexer to separate the IF output from the RF input.

PHYSICAL CIRCUIT CONFIGURATION

A top view photograph of the 40 GHz mixer and the 10:1 4 GHz scale model are shown in Figure 1. The circuit consists of the antiparallel bridge, series mounted between two tapered microstrip baluns which transform unbalanced LO and RF inputs to balanced signals at the diode terminals. The baluns, designed to maintain a constant impedance of 50 ohms at each cross section along the structure's length, are fundamental to the unit's broadband performance. Balun low frequency behavior is limited by physical length. Lengths greater than one tenth wavelength at the lowest LO input frequency are required for acceptable conversion performance. High frequency operation, typically limited by even mode resonant effects (4), can be extended by judicious choice of substrate dielectric and proper termination of even mode current paths.

The mixer's 1 GHz IF response simplifies circuit topology by allowing efficient extraction of the IF signal in an unbalanced fashion using a diplexer. The diplexer is realized as a parallel

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arrangement of lumped element, low-pass and high-pass filters (5), whose component selection and characterization is critical in maintaining resonant free performance to 40 GHz. It is necessary to use three turn airwound coils of .001" diameter wire, and 1.0 pF beam lead capacitors to achieve this goal. Mechanical self-resonance of the miniature coil is damped by a low loss resin.

The physical model of the mixer, presented in Figure 2, is transformed into the electrical model of Figure 3 by a numerical TEM or static capacitance program based on results of a workshop given by Harrington (6). The method of moments is used to determine an equivalent charge model for each conductor in a multiconductor/dielectric system, after specifying the geometry and potential of each conductor. Figure 4 illustrates the procedure whereby a prescribed physical balun section is transformed into its electrical equivalent (7).

The mixer's conversion performance may be predicted using the electrical model of Figure 3, the nonlinear time domain simulation program, SPICE, and a discrete fast Fourier transform (DFFT) program. SPICE is used to evaluate the large signal, time varying diode junction voltage and nonlinear current at discrete points in a given LO cycle. This data is used to determine the small signal junction resistance and capacitance needed to obtain the desired RF port time varying reflection coefficient, Grf(t). The DFFT program yields Grf(f), the frequency domain RF port reflection coefficients, from which theoretical conversion loss is obtained.

EXPERIMENTAL RESULTS

Measured results are presented in Figure 6 for the diplexer alone and completed mixer, together with theoretically predicted points, based on the SPICE simulation. The predicted data point at 20 GHz required 17 hours of CPU time using a Compaq Deskpro 386 personal computer. However, recently available "harmonic balance" software depicted in Figure 5, should decrease this run time considerably.

The measured input third order intercept point (IP3) was +12 dBm, with a LO power of +14 dBm. An advantage of second harmonic mixing is inherently high LO to RF isolation. Furthermore, the 2LO to RF isolation of greater than 50 dB is adequate for many receiver applications and eliminates the need for external isolators.

CONCLUSION

A broadband second harmonic mixer has been developed which operates over a 4 to 40 GHz RF band, with less than 12 dB conversion loss and +12 dBm input IP3, at a LO power of +14 dBm. Experiments have shown that traditional development techniques, such as frequency scaling, can yield useful conclusions about very high frequency devices, and in particular, that lumped elements perform acceptably at millimeter frequencies.

The second harmonic mixer is still the most desirable front-end for millimeter wave receivers, including missile seekers, due to very low LO reradiation and conversion loss.

Future efforts include extending IF bandwidths to 3, 6 and 12 GHz, with RF coverage from 8 to 40, 18 to 40, and 26 to 40 GHz, respectively.

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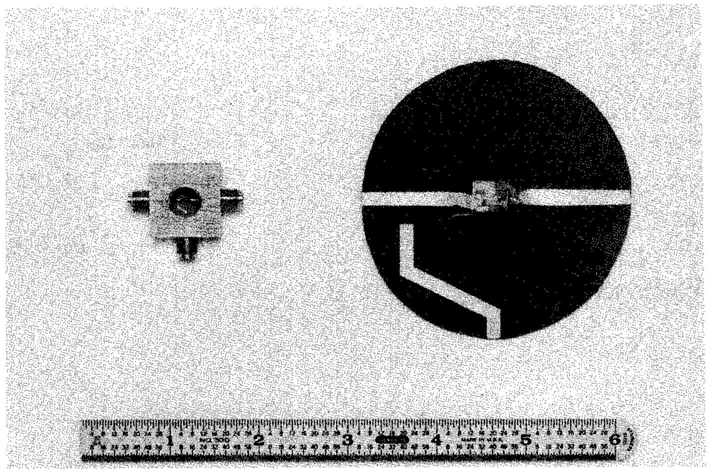


Fig. 1. Photograph of 40 GHz mixer and 4 GHz scale model.

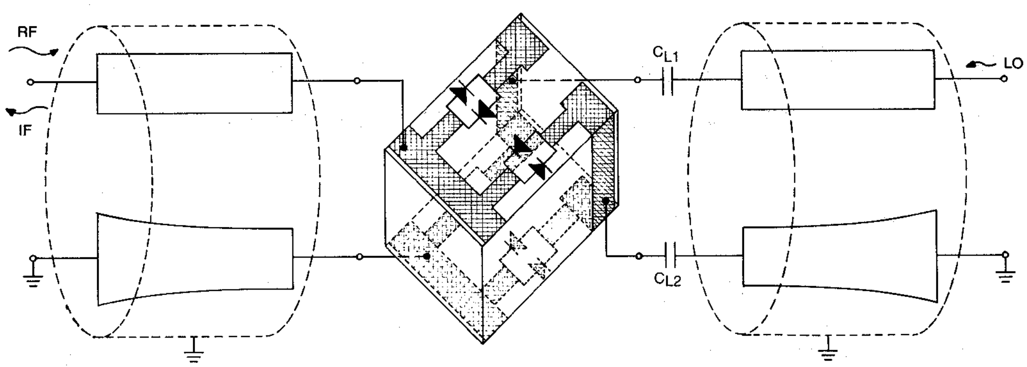


Fig. 2. Physical mixer model (excluding diplexer).

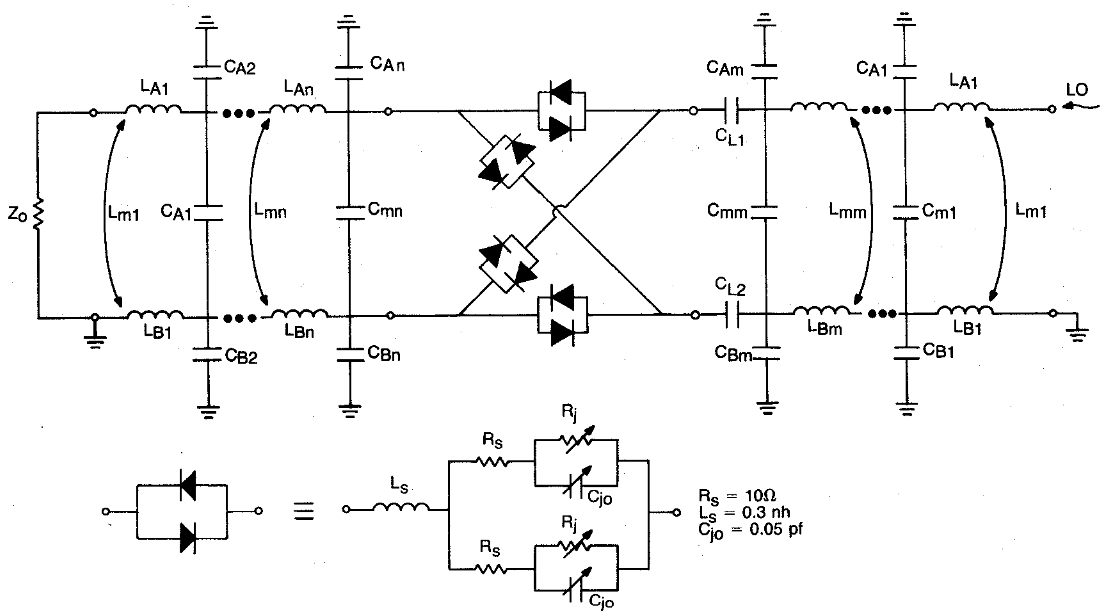
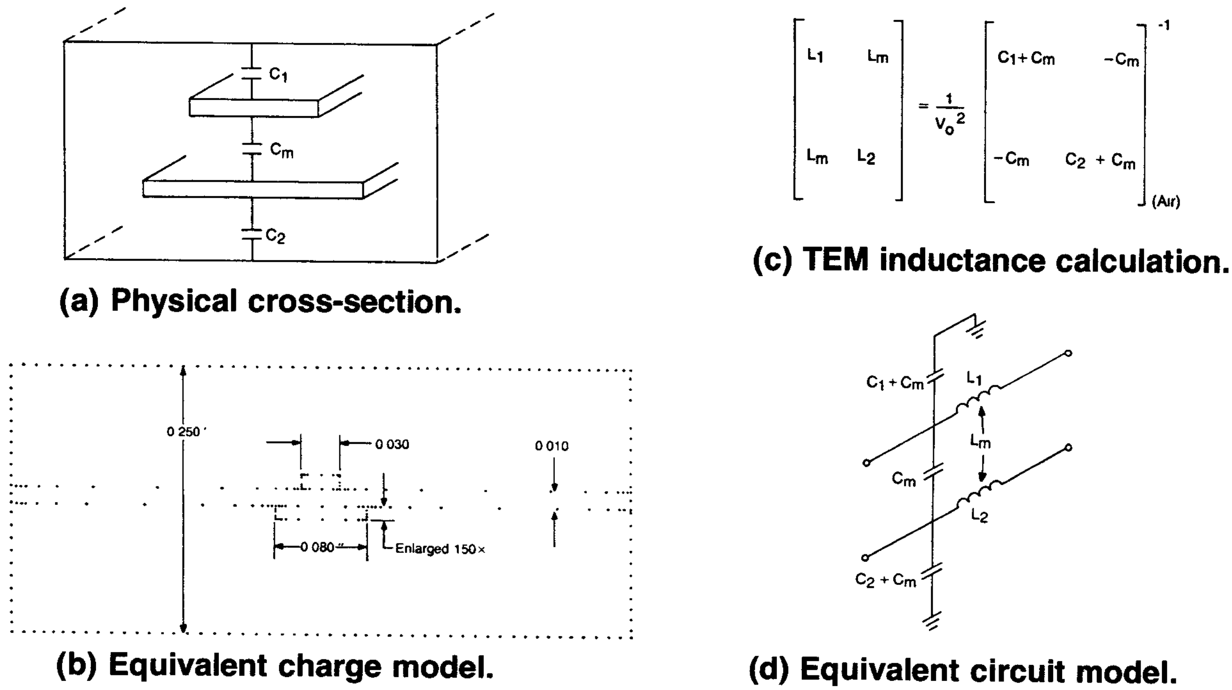


Fig. 3. Electrical mixer model (excluding diplexer).



$$\begin{bmatrix} L_1 & L_m \\ L_m & L_2 \end{bmatrix} = \frac{1}{V_o^2} \begin{bmatrix} C_1 + C_m & -C_m \\ -C_m & C_2 + C_m \end{bmatrix}^{-1}_{(Air)}$$

(a) Physical cross-section.

(b) Equivalent charge model.

(c) TEM inductance calculation.

(d) Equivalent circuit model.

Fig. 4. L/C equivalent of balun section.

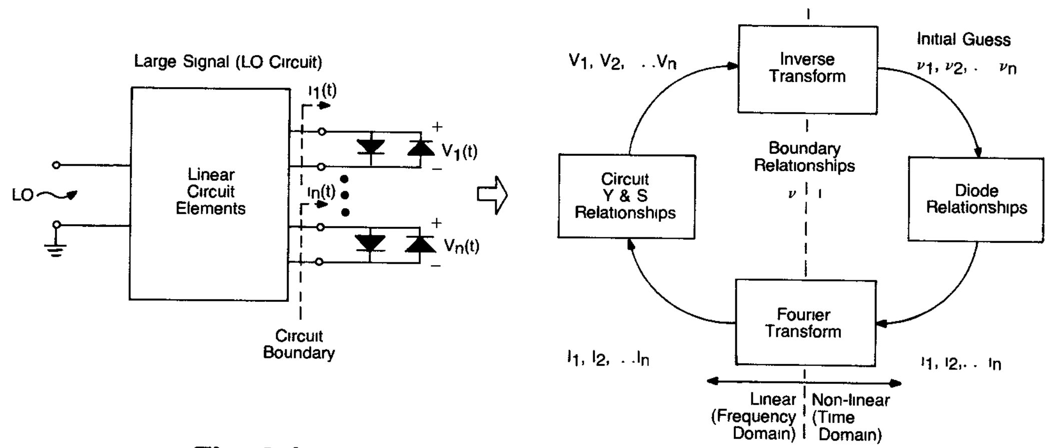


Fig. 5. Large signal diode *ν* and *i* calculation.

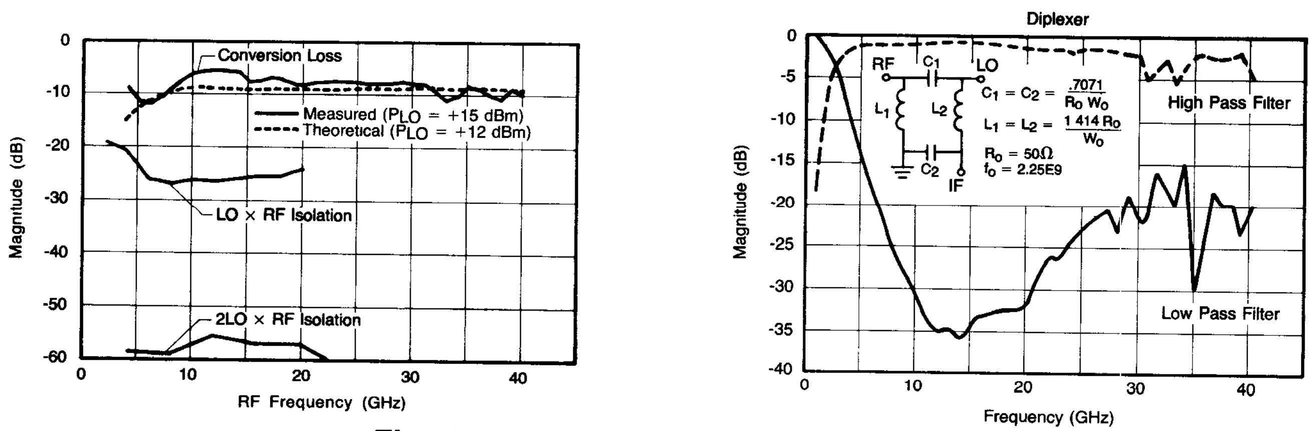


Fig. 6. Measured performance data.