A Broad-Band Second-Harmonic Mixer Covering 76–106 GHz

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***Abstract*—A broad-band second-harmonic millimeter-wave mixer has been constructed. The circuit consists of a single unencapsulated Schottky-barrier diode and an embedding network which includes a wave absorber in the IF output terminal. The conversion loss of the mixer is 14.6±0.9 dB over a frequency range of 76–106 GHz. The mixer is pumped by a local oscillator that is tuned over the range of 37.15–52.15 GHz. The IF is kept constant at 1.7 GHz. The new mixer looks attractive for use in broad-band millimeter-wave measuring equipment, such as spectrum analyzers.**

I. Introduction

It has been shown by several workers that the technique of subharmonic pumping (or harmonic mixing) is very useful at millmeter-wave frequencies where fundamental local-oscillator power sources may be too costly, or not practical for a particular system [1]–[7]. The study of such mixers involves the following two areas of investigation: 1) minimizing the mixer noise temperature and conversion loss, and 2) obtaining a broad RF bandwidth. A large bandwidth is very important if the mixer is used for broad-band measuring purposes, such as for spectrum analyzers. In previous reports on harmonic mixers, major effort has been directed toward minimizing mixer noise temperature and conversion loss over the relatively narrow bandwidth. Achieving full waveguide band operation was not addressed.

In a previous report [8], one of the authors has proposed a new broad-banding technique using a wave absorber in the IF circuit and has proved its practicability with a 60–90-GHz fundamental mixer. It is the purpose of this paper to describe how this broad-banding technique has been extended to harmonic mixers in the higher frequency region, and to demonstrate the broad-band characteristics with an experimental mixer. The mixer is operated in the 100-GHz band, pumped by a tunable 50-GHz-band local oscillator. The IF is fixed at 1.7 GHz. A single unencapsulated GaAs Schottky-barrier diode is used. The diode mount has a crossed-waveguide configuration. Circuit construction, conversion loss versus bias voltage, and frequency response of the experimental mixer are described in detail.

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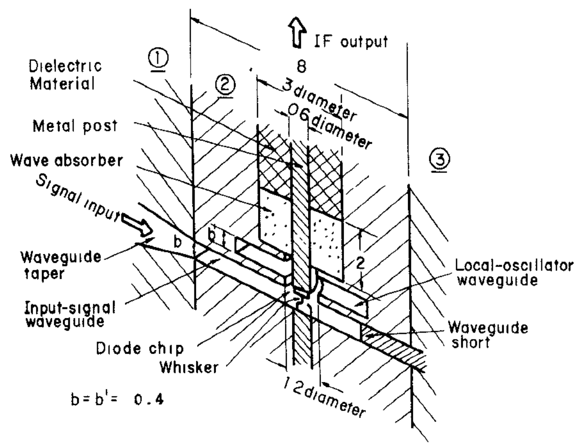

Fig. 1. Cross-sectional view of the harmonic mixer. ① Two waveguide-taper transitions. ② A diode mount. ③ Two waveguide shorts. A crossed-waveguide configuration is used. A single unencapsulated diode is mounted directly in the waveguide. A wave absorber is embedded in the IF coaxial circuit. All dimensions are presented in millimeters.

II. Circuit Description

A. Outline

The inside structure of the mixer is shown in Fig. 1, and a photograph of the complete mixer is shown in Fig. 2. The mixer circuit consists of three major parts ① two waveguide-taper transitions, ② a diode mount, and ③ two waveguide shorts. The taper transitions provide impedance matching between the standard- and reduced-height waveguides. The diode mount is located at the intersection of the input-signal and local-oscillator waveguides. The respective widths of the two waveguides are the same as the standard-size WR-10 and WR-19 waveguides (Table I). The waveguide shorts are used for matching the diode to the waveguides.

The IF circuit is made of a coaxial line with a characteristic impedance of 50 Ω. A wave absorber is embedded in the IF circuit. A coaxial filter is not used.

B. Wave Absorber Insertion

The wave absorber is used in the IF line to prevent the harmful effect caused by the reflection of the input-signal and local-oscillator powers leaked into the IF coaxial line from the waveguides. The absorber used is a material

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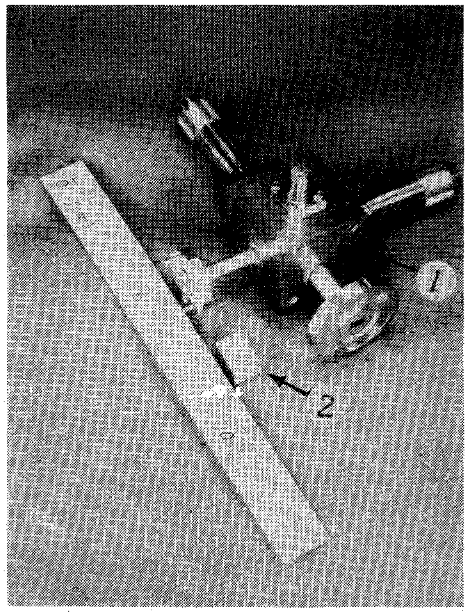

Fig. 2. Photograph of the harmonic mixer. ① A mixer mount including two waveguide-taper transitions and two waveguide shorts. ② A waveguide wafer in which a diode is mounted. The waveguide wafer is embedded in the mixer mount when the mixer is operated.

TABLE I

Waveguide	The standard frequency band	Inside dimension
The WR-10 waveguide	75 GHz – 110 GHz	2.540 mm × 1.270 mm
The WR-19 waveguide	40 GHz – 60 GHz	4.775 mm × 2.388 mm

made by solidifying carbonyl-iron powder with epoxy resin. The amount of carbonyl iron is 85 percent by weight percent, and its grain diameter is about 2 μm. The measured loss of the absorber material is 5–10 dB/cm.[1] The dimensions of the absorber material used in the experimental mixer are shown in Fig. 1.

C. Diode Fabrication

The GaAs Schottky-barrier diode used has a honeycomb structure, and its junction diameter is 3 μm. Approximate series resistance and zero-voltage junction capacitance of the diode are 13 Ω and 0.015 pF, respectively. (Excess series resistance due to the wave absorber is not included.) The contact to the diode is made by pressing a spring-loaded whisker using a short AuGa wire against one of the small junctions on the surface of an oxide-protected chip. The whisker is 25 μm in diameter, and is electrolytically sharpened to a tip radius of about 1 μm. For easy fabrication, the metal post supporting the diode chip is used as a common center-conductor to the two coaxial lines, i.e., one is the IF coaxial line and the other is the coaxial line through which the two reduced-height waveguides are coupled to the diode.

D. Minimization of Parasitics and Impedance Matching

The factors which restrict the RF bandwidth are: 1) shunt capacitance of the diode mount, and series inductance due to the whisker, and 2) reactance due to tuners and filters. It is apparent that the excess capacitance and inductance increase the circuit Q and decrease the RF bandwidth accordingly. In order to minimize parasitic parallel capacitance and series inductance, an unencapsulated diode is mounted directly in the waveguide, and the whisker is shortened to the practical fabrication limit of a total length (the expanded length) of 300 μm. The calculated whisker inductance is approximately 0.2 nH [10]. Moreover, the diode-holder structure is made as simple as possible, that is, no stub tuners or waveguide filters are used.

The impedance matching between the diode and the waveguides is obtained by reducing the waveguide height to 400 μm and adjusting the two waveguide shorts.

[1]This is a measured value of insertion loss for the absorber material mounted in rectangular waveguides in a 40–90-GHz range [9].

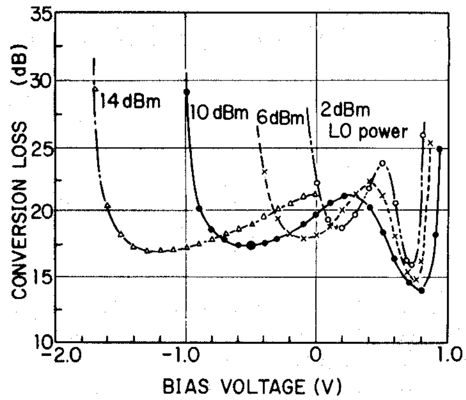

Fig. 3. Conversion loss versus bias voltage for various values of local-oscillator power. At the specified bias voltage and local-oscillator power marked with a sign ◉ in the figure, the two waveguide shorts of the input-signal and local-oscillator waveguides are adjusted beforehand to the optimum point that gives a minimum conversion loss. Then these waveguide shorts are fixed for other values of bias voltage and local-oscillator power. (Input-signal frequency = 100 GHz. Local-oscillator frequency = 49.15 GHz. IF = 1.7 GHz.)

III. Experimental Result

A. Measuring Setup

The mixer is operated as an upper sideband downconverter pumped by the second harmonic of the local-oscillator frequency. The IF is fixed at 1.7 GHz. Two reflex klystrons are used as the input-signal source and the local-oscillator source. The mixer is supplied with dc bias through the IF port. A dc block tee separates the IF circuit from the dc circuit. Thermocouple power meters are used in the RF and IF power measurements.

B. Conversion Loss Versus Bias Voltage

Measured conversion loss versus bias voltage for various values of local-oscillator power is given in Fig. 3. At the specified bias voltage and local-oscillator power indicated in the figure, the two waveguide shorts of the input-signal and local-oscillator waveguides are adjusted beforehand to the optimum point that gives a minimum conversion loss. Then these waveguide shorts are fixed for other values of bias voltage and local-oscillator power.

Two minimum values of conversion loss are observed for a given local-oscillator power. (No such phenomenon has been observed in the fundamental mixer previously reported by one of the authors [8].) The smallest values of conversion loss are obtained at a forward bias voltage of about 0.7 V. The bias dependence is more critical when the mixer is forward biased. As the local-oscillator power increases, the second minimum point moves in the negative bias direction. Thus the conversion loss characteristics versus bias voltage of harmonic mixers show fairly complex curves. Consequently, careful bias adjustment is required for a given local-oscillator power in order to obtain efficient and broad-band characteristics.

C. Frequency Response

Fig. 4 shows the frequency response for the two different bias voltages which give the minimum value of conversion loss in Fig. 3. In this measurement, the input-signal and local-oscillator frequencies are changed simultaneously so as to keep the IF constant at 1.7 GHz. The two waveguide shorts of the input-signal and local-oscillator waveguides are adjusted beforehand to the optimum point that gives a minimum conversion loss at 100 GHz. Then these waveguide shorts are fixed for other frequencies. The spacing between the diode plane and the short plane is 0.25–0.40 λ_g (λ_g is the guide wavelength) for both the input-signal and local-oscillator waveguides. The bias voltage and local-oscillator power are kept constant at the values given in Fig. 4 over the measured frequency range.

Both bias voltages 0.68 and -0.5 V give similar frequency responses. The forward bias voltage, however, gives a smaller conversion loss over the measured frequency range than the backward one. The conversion loss is 14.6 ± 0.9 dB over a frequency range of 76–106 GHz for a bias voltage of 0.68 V and a local-oscillator power of 8 dBm.

IV. Conclusion

Circuit construction and experimental results of a broad-banded millimeter-wave second-harmonic mixer using a wave absorber in the IF circuit have been discussed. The broad-band frequency response covering 76–106 GHz has been measured. This type of harmonic mixer will be useful in millimeter-wave instrumentation, such as spectrum analysis.

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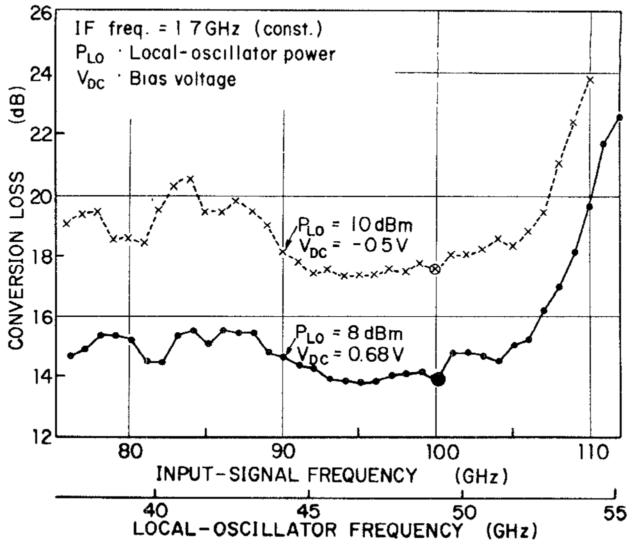

Fig. 4. Frequency responses. The input-signal and local-oscillator frequencies are simultaneously changed to keep the IF frequency constant at 1.7 GHz. The two waveguide shorts of the input-signal and local-oscillator waveguides are adjusted beforehand to the optimum point that gives a minimum conversion loss at 100 GHz. Then these waveguide shorts are fixed for other frequencies.

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