The series resonance of L and $C_D + C_t$ requires an infinite susceptance at the diode terminals, BB', at $\omega = \omega_s$ and hence requires the tuning curve to intersect with the $\lambda_g/2$ reference curve and the output power profile to dip, as expected from and evidenced by (1) and (2) and Figs. 2 and 3, respectively. If desired, characterization of the packaged diode under actual operating conditions is possible from the measured tuning curve and output power profile with the aid of (1) and (2). Methods of obtaining the output power at ω_s are currently under investigation.

Conclusion

A new method of construction of the Gunn oscillator for wide-band frequency tuning has been developed using the ridged-waveguide cavity. The ridged waveguide can be designed to provide the dominant mode with a wide bandwidth and to provide the cutoff modes with reduced reactive energies to permit wide-band operation of the oscillator. An experimental oscillator was tunable continuously from 8 to 18 GHz, demonstrating the validity of the method. The approach presented in this paper will be applicable to designs of various broad-band microwave circuits involving small devices other than the Gunn diode.

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Design and Performance of a 60–90-GHz Broad-Band Mixer

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***Abstract*—This short paper describes a practical design and performance of 60–90-GHz broad-band mixers. Conversion loss was less than 11 dB in the 60–90-GHz region, and the conversion-loss deviation could be less than about 1 dB throughout the 30-GHz band with fixed circuit parameters. In this design, a new construction technique, using a wave absorber in place of a filter in the IF circuit, was employed.**

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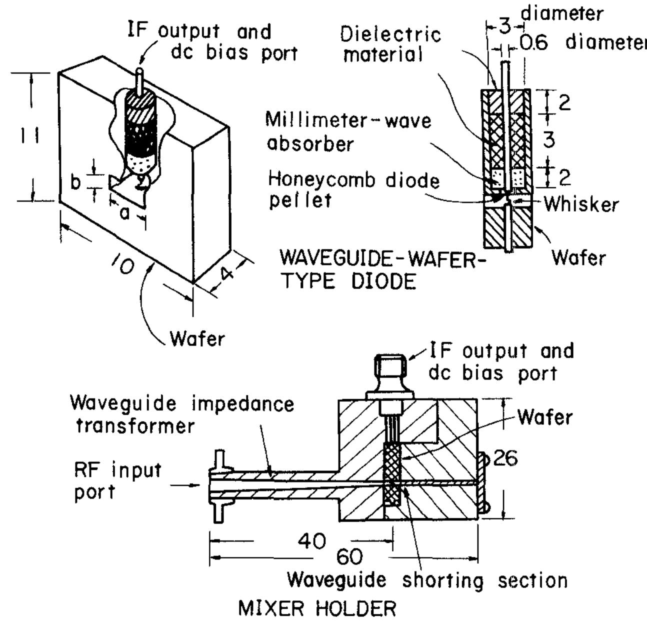

Fig. 1. Construction of a 60–90-GHz broad-band mixer. All measurements in millimeters.

I. Introduction

When referring to a broad-band mixer (receiving frequency converter), the following two cases are pertinent: 1) a mixer characterized by a broad IF bandwidth with a constant local-oscillator frequency; and 2) a mixer characterized by a broad RF bandwidth with a constant IF. The usefulness of the previous two mixer cases depends on the purposes of their applications. For example, the former is necessary for a millimeter-wave communications system, and for this application millimeter-wave mixers with a 1-GHz IF band have been reported [1]–[3]. For application to millimeter-wave measuring equipment, such as a selective levelmeter or a spectrum analyzer, however, the latter is important in order to cover the millimeter-wave band broadly and increase the sensitivity of the equipment by narrow-band signal receiving. In this case, mixers with a millimeter-wave band above 10 GHz are necessary. However, no investigations about them have been reported.

This short paper represents a design and performance of broad-band mixers characterized by a broad RF bandwidth for application to millimeter-wave measuring equipment. A broad-band mixer characterized by a broad IF bandwidth could also be obtained by the same method [4].

II. Design of a 60–90-GHz Broad-Band Mixer

A. Mixer Diode

In the millimeter-wave region, because of the large parasitic reactances, it is difficult to obtain broad-band characteristics by means of a pill-type diode package, which is generally used in the microwave region. For this reason, the "waveguide-wafer-type diode," as shown in Fig. 1, is widely used [1]–[3]. In this short paper, an image impedance-matched waveguide-wafer-type mixer using a GaAs Schottky-barrier diode with a junction diameter of 3 μm is presented. Computed values of the diode impedance (Z_d) for matching to the local oscillator were (49–j62) Ω at 60 GHz and (37–j49) Ω at 90 GHz (Table I) [5].

B. RF Circuit

A whisker 20 μm in diameter and 320 μm in length, was employed. The waveguide width a is 3.099 mm. Thus the equivalent inductance of the whisker is about 0.3 nH [6]. In this case,

TABLE I
NUMERICAL VALUES OF PARAMETERS USED IN THE CALCULATIONS

D (junction diameter) = 3 (μm)
Is (reverse saturation current) = 1.995 × 10^{-14} (A)
C_0 (junction capacitance at zero bias) = 0.025 (pF)
Rs (series resistance) = 20 (Ω) [a]
φ (barrier voltage) = 1.0 (V)
η (quality factor related to Schottky barrier junction) = 1.2
γ (slope factor of the junction capacitance) = 0.25
forward dc voltage of the mixer diode = 0.3 (V)
local oscillator power = 6 (dBm)

[a] R_s took the value of 20 Ω in the measurement at low frequency. The value of R_s is independent of frequency by [7].

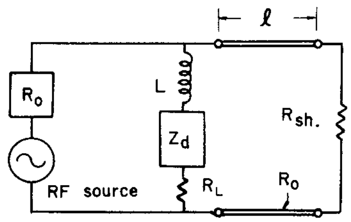

Fig. 2. Millimeter-wave equivalent circuit of a mixer. L—whisker inductance (~0.3 nH); Z_d—diode impedance; R_0—characteristic impedance of the waveguide; R_{sh}—resistance of the waveguide shorting section; $R_{sh}/R_0 = (a/2b)(1/20)$,* where a and b represent the width and height of the waveguide, respectively; R_L—equivalent resistance of the waveguide-to-coaxial-line transition (~10 Ω);* l—spacing between the waveguide short and the diode plane. *—measured values.

the optimum waveguide height for the broad-band characteristic is about 0.4 mm, from the calculation of mismatch loss using an equivalent circuit including the mixer diode, parasitic elements, and the input waveguide circuit (Fig. 2). Trial mixers were designed with two values of the waveguide height b, 0.4 mm and 0.8 mm, to compare their frequency responses. The input waveguide (R-740), 40 mm in length, is tapered to a height of 0.4 mm or 0.8 mm for matching purpose, which is characterized by a VSWR of less than 1.1 all over the 60–90-GHz region. The optimum value of the spacing between the waveguide short and the diode plane is dependent upon the waveguide height, diode impedance, and parasitic elements. For this mixer the value can be computed to be 0.36 times the guide wavelength at 83 GHz. During the measurements the spacing was adjusted at that frequency for minimum conversion loss, and agreed well with the computed result.

C. IF Circuit

Most of the millimeter-wave mixers have a coaxial or radial-line filter in the IF circuit to prevent leakage of millimeter waves into the IF circuit. In the case of the broad-band mixer, however, it is feared that the reflection in the filter influences the total frequency response of the mixer; therefore, the design of the filter is usually difficult. The design of the filter also requires consideration of higher propagation modes. In order to avoid the influence of higher order mode propagation, the cutoff wavelength (λ_{11c}) of the lowest mode TE_{11} in the coaxial waveguide, which is given by the following equation, must be shorter than

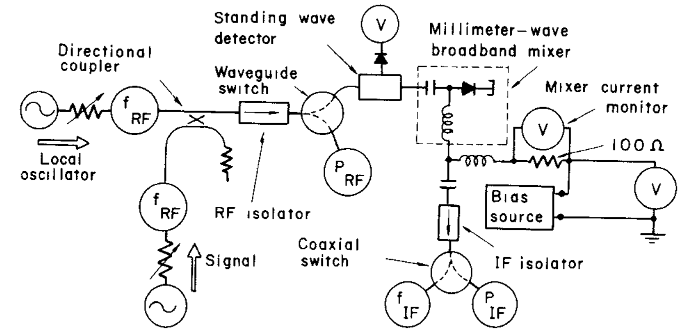

Fig. 3. Measuring equipment configuration. f_{RF}—RF frequency meter: P_{RF}—RF power meter: f_{IF}—IF frequency meter: P_{IF}—IF power meter.

the wavelength (λ) of the millimeter-wave used:

$$\lambda_{11c} \cong \pi \cdot (r_1 + r_2) < \lambda \qquad (1)$$

when using a filter in the IF circuit. Here $2r_1$ and $2r_2$ are the diameters of the outer and the inner conductors of the coaxial waveguide, respectively. For example, $r_1 + r_2$ must be less than 0.95 mm for a cutoff frequency of 100 GHz, bringing about a problem in production capability and mechanical stability; therefore, it is difficult to avoid the influence of the propagation modes. In practice, a mixer using a filter is characterized by a narrower bandwidth and an increase of conversion loss outside the usable frequency band.

Accordingly, a new construction technique was employed, using a millimeter-wave absorber in the IF circuit, as shown in Fig. 1, in place of a filter. This absorber was a substance made by solidifying carbonyl iron powder with epoxy resin, though careful consideration should still be given to other millimeter-wave absorbers. Mixers using this method of IF circuit construction are characterized by the following properties.

1) The millimeter-wave absorber prevents leakage of millimeter waves into the IF circuit.

2) The quality factor Q of the mixer is lowered by the equivalent resistance of the millimeter-wave absorber, which is in series with the mixer diode; therefore, a broad frequency band can be obtained more easily.

3) The millimeter-wave absorber prevents higher mode propagation in the coaxial IF circuit. This property makes the design of the IF circuit free from (1), which limits the coaxial waveguide size. The practical size of the IF circuit is given in Fig. 1.

III. PERFORMANCE OF THE 60–90-GHz MIXER

A. Measuring Equipment

Fig. 3 illustrates the configuration of the measuring equipment. The mixer was operated as an upper sideband down-converter. The intermediate frequency was kept at 1.7 GHz.

Millimeter-wave broad-band isolators, characterized by isolation of more than 20 dB and a VSWR of less than 1.1 throughout the available frequency band were used as RF isolators [8].

B. Performance

Figs. 4–6 show the experimental results of the 60–90-GHz broad-band mixers. Frequency responses with fixed circuit parameters (diode bias, local-oscillator power, and the spacing

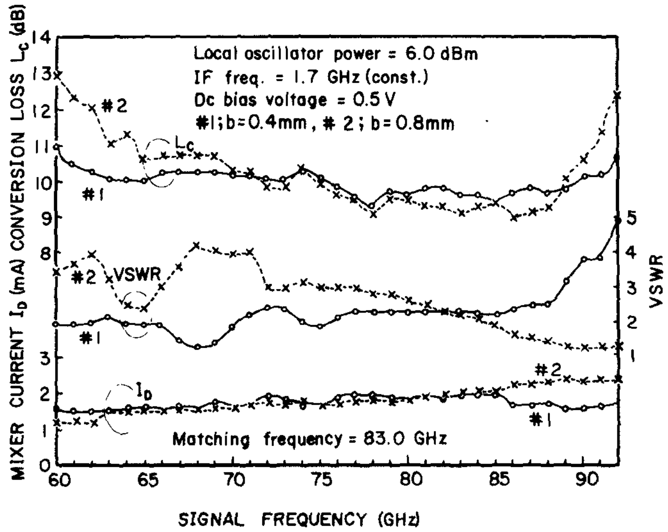

Fig. 4. Measured frequency responses of 60–90-GHz broad-band mixers

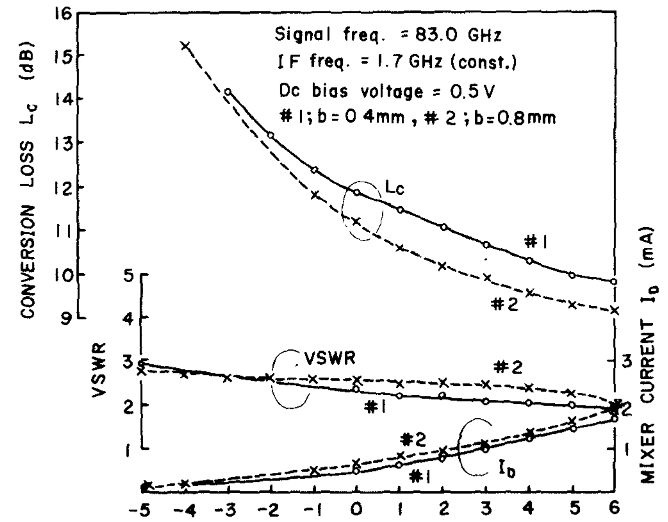

Fig. 5. Conversion loss, mixer current, and VSWR as functions of local-oscillator power.

between the waveguide short and the diode plane) are given in Fig. 4. From Fig. 4 it is obvious that the waveguide height of 0.4 mm is more suitable for this 60–90-GHz broad-band mixer than a height of 0.8 mm. For mixer 1 ($b = 0.4$ mm), conversion loss is less than 11 dB in the 60–90-GHz region and the conversion-loss deviation can be less than about 1 dB throughout the 30-GHz band. This result signifies that the 60–90-GHz region, which is the normal frequency range of R-740 waveguide circuits (by IEC) can only be covered by mixer 1. The flat frequency responses regarding the mixer current imply the possibility of a millimeter-wave broad-band detector. The VSWR characteristics at the local-oscillator port have a few undulations. This is not, however, a serious problem, because millimeter-wave broad-band isolators (for instance, the Hughes Model 44605H) can be easily used today.

Figs. 5 and 6 show conversion loss, mixer current, and VSWR as functions of local-oscillator power and dc bias voltage, respectively. From these figures, it is seen that mixer 1 is better impedance matched than mixer 2. In this measurement, as

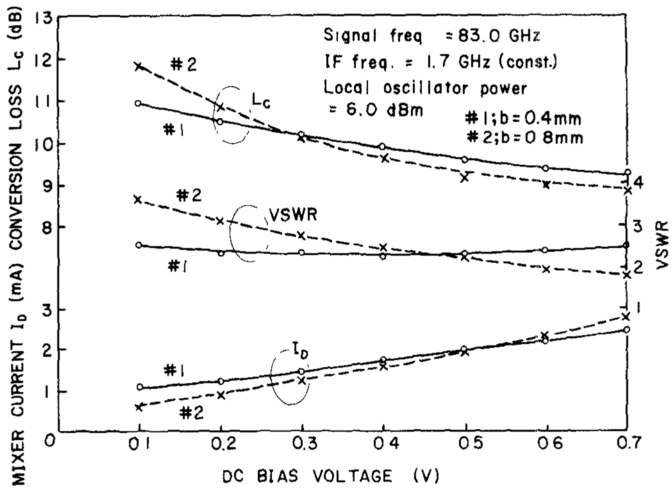

Fig. 6. Conversion loss, mixer current, and VSWR as functions of dc bias voltage.

shown in Fig. 3, a 100-Ω resistance is connected between the diode and the constant dc bias supply to measure the mixer current from the voltage across the resistance. Thus the practical forward dc voltage of the mixer diode is given by

$$V_{dc} = V' - I_D \times 10^{-1} \quad \text{(V)}$$

where V' (V) is the dc bias voltage given by Figs. 4–6, and I_D is the mixer current (mA).

IV. Conclusion

A practical design and performance of 60–90-GHz broad-band mixers was presented. A full-band characteristic in the 60–90-GHz region was obtained, which will be very useful in measuring equipment.

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