Millimeter-Wave Thin-Film Downconverter

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Abstract—**A 60-GHz hybrid integrated downconverter intended for use in a millimeter-wave radio relay experiment has been designed and tested. The converter consists of a strip transmission line circuit and two beam-leaded Schottky-barrier diodes which are pumped at a subharmonic of the conventional local oscillator frequency. The conversion loss of the circuit is 6.3 dB and the total single-sideband noise figure, including the noise contribution from the IF amplifier, is 9.1 dB. The circuit looks attractive for millimeter-wave communication systems application up to 100 GHz.**

I. Introduction

THE purpose of this paper is to describe the design and performance of a hybrid integrated downconverter for use in a frequency-shift-keyed (FSK) receiver for short hop radio systems [1]. The downconverter has a basic similarity to a microwave integrated circuit which has been built at a much lower signal frequency, 35 GHz [2]. A similar circuit which is built in a microstrip medium has also been described by Cohn *et al.* [3]. There are a number of significant differences, however, which have been introduced to solve the additional problems associated with operating at millimeter wavelengths. Among these features are the use of beam-leaded millimeter-wave diodes, a low-loss transition from the signal waveguide to the stripline, and a stripline band-reject filter for separating the IF frequency from the subharmonic pump frequency. It is thus much less complex than a waveguide converter and can be produced using conventional photolithographic processing techniques.

II. Description of Thin-Film Circuit

A block diagram of the thin-film circuit is shown in Fig. 1. The downconverter consists of a signal waveguide which is coupled to a strip transmission line by means of a capacitive probe. The signal is transmitted through a bandpass filter to a pair of beam-leaded diodes which are shunt mounted in the stripline with opposite polarities. This is followed by a low-pass stripline filter, an inductive coupling section to the pump waveguide, and a band-reject stripline filter which transmits the IF frequency and rejects the pump frequency. The pump or local oscillator frequency is approximately half the signal frequency, thus the pump waveguide is about twice the size of the signal waveguide. A more detailed drawing of the circuit and a cross-sectional view of the stripline is shown in Fig. 2. Fig. 3 is a photograph of the circuit. The stripline is mounted in a small brass block which contains a short section of the signal waveguide and the pump waveguide. A movable short in each waveguide is used to match the incoming signal and the local oscillator power to the strip transmission line circuit; these shorts are not visible in the photograph. The diodes are bonded to the conductor pattern on opposite sides of the stripline. A small conductor tab is used on each side to provide contacts to the metal housing. A dc return is not needed since optimum performance can be achieved without dc bias.

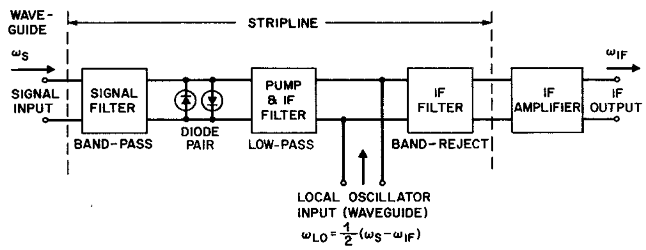

Fig. 1. Block diagram of signal input in waveguide, stripline circuit, pump input, and IF amplifier.

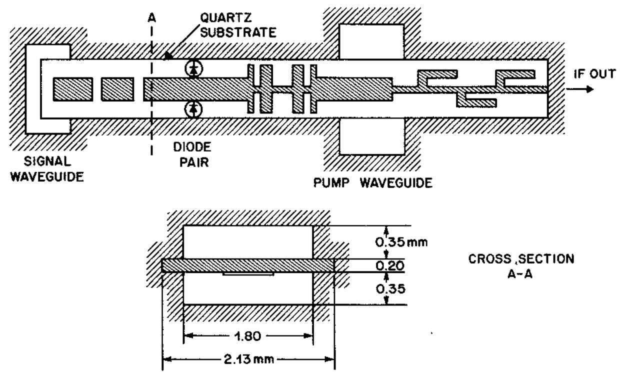

Fig. 2. Top view of stripline circuit in metal housing and cross-sectional view of strip transmission line. The diodes are shunted to ground at opposite sides of the stripline. The input signal is capacitively coupled to the stripline, and the pump is inductively coupled to the stripline.

III. Stripline Filters

Three stripline filters are used on a fused quartz substrate with a thickness of 0.18 mm, a width of 2.0 mm, and a total length of 22 mm. The bandpass filter is a half-wavelength resonator; the low-pass filter consists of alternate capacitive and inductive line sections. These two filters are discussed in more detail in a recent paper [2]. The third filter is needed to separate the local oscillator and the IF. This band-reject filter consists of three staggered open stripline stubs with a length of approximately one quarter-wavelength at the pump frequency. The filter was first designed at a frequency of 1.7 GHz and subsequently scaled to the desired pump frequency of 29 GHz.

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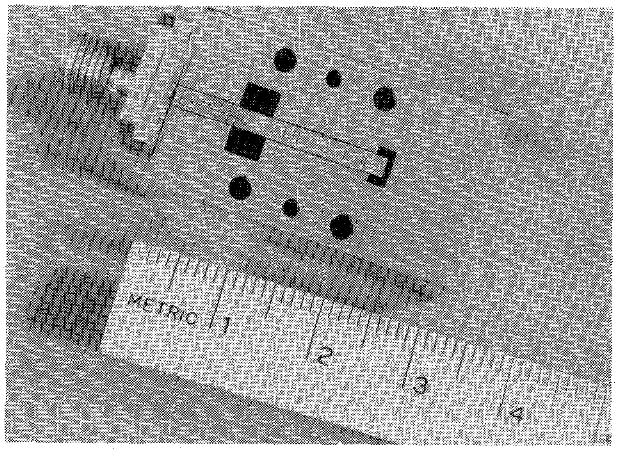

Fig. 3. Photograph of downconverter with a signal frequency of 60 GHz and a pump frequency of 29 GHz. The top cover of the housing is removed to show the conductor pattern on the dielectric substrate.

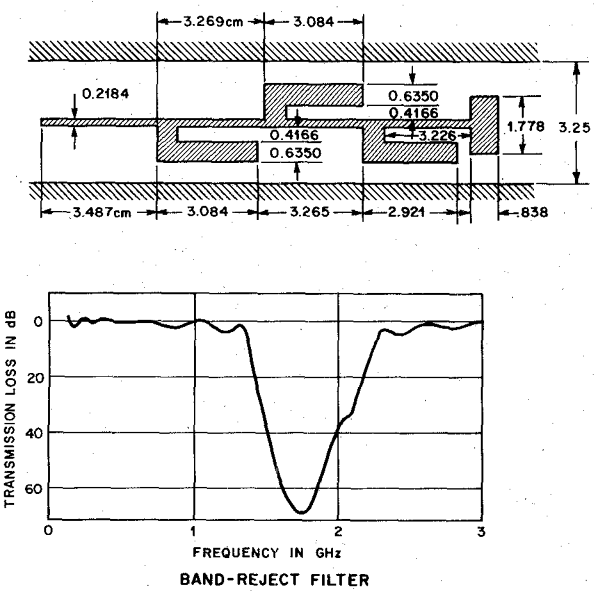

Fig. 4. Dimensions and performance of the low-frequency model of the band-reject filter. The filter was subsequently scaled to the millimeter-wave frequency range by a scaling factor of $17x$.

The dimensions and the measured performance of the low-frequency model are given in Fig. 4. The maximum measured transmission loss is 70 dB at the pump frequency and less than 0.1 dB at the IF frequency.

IV. Diode Pair

Beam-leaded diodes are ideally suited for use in strip-line receivers because they are operated at a relatively low RF power and can be readily bonded to the stripline conductor. It should be noted, however, that conventional beam-leaded devices have a relatively large parasitic overlay capacitance which must be compensated by tuning elements in the external embedding network to obtain the required match at the signal and the local oscillator frequencies. This results in additional losses and a reduction of the bandwidth of the downconverter.

Beam-leaded devices with substantially reduced parasitics have been recently devised by Cho and Ballamy [4].

TABLE I
Electrical Characteristics of Diode Pair

GaAs Slice RSE-6A	Diode A2	Diode A3
Series Resistance R_s Ohm	7.0 Ω	7.3 Ω
Junction Capacitance C_o pF at 0 Volt	0.020	0.020
Overlay Capacitance C_F pF	0.037	0.037
Breakdown at 10μA	5.4 V	4.2 V
Idealty Factor $n = \frac{q}{KT}\frac{\partial V}{\partial(\ell n I)}$	1.30	1.30

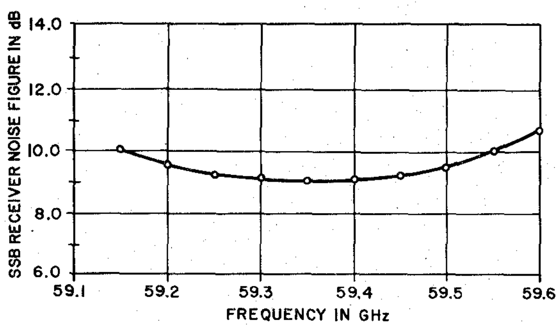

Fig. 5. Total single-sideband noise figure of millimeter-wave receiver including the 2.8-dB noise contribution from the IF amplifier. The IF amplifier has a gain of 25 dB at 1.4 GHz.

These devices consist of polyisolated islands of epitaxial gallium arsenide which are grown on a chromium-doped insulating GaAs substrate. Devices of this type are used in the downconverter described in this paper. The electrical characteristics of two diodes used in the circuit are given in Table I. The cutoff frequency for each diode is approximately 1000 GHz. It is expected that further improvements in the quality of the polyisolated epitaxial material and refined processing techniques will give a cutoff of 2000 GHz, which should result in a substantial improvement of the currently obtained conversion loss and single-sideband noise figure.

V. Performance of Downconverter

The single-sideband noise figure measured at 59.3 GHz is shown in Fig. 5. The total single-sideband noise figure of 9.1 dB includes a 2.8-dB noise contribution from the IF amplifier which has a gain of 25 dB at 1.4 GHz. The corresponding local oscillator frequency is 29 GHz. The conversion loss in decibels as a function of the local oscillator power is shown in Fig. 6. A conversion loss of 6.3 dB is obtained for a pump power of 15 dBm which corresponds to a power of 15 mW for each diode. The bandwidth for a noise figure degradation of 1 dB is 400 MHz. This is sufficient for digitally modulated FSK or PSK systems with modulation rates of up to 300 MBb. The local oscillator AM noise sidebands in the mixer are suppressed [5], and

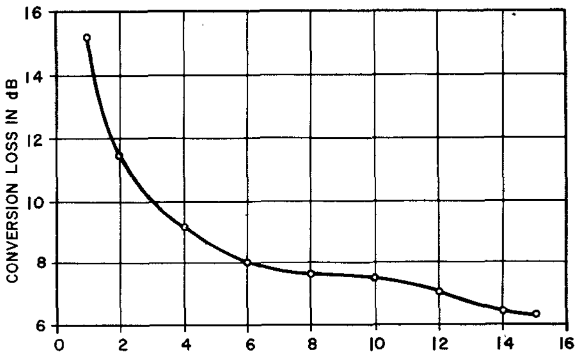

Fig. 6. Conversion loss of downconverter as a function of the pump power of the subharmonic local oscillator. The conversion loss at a power of +15 dBm or 15 mW per diode is 6.3 dB.

the circuit also shows good pump-to-signal port isolation. The pump frequency does not reach the signal input port because it is below cutoff in the signal waveguide and the second harmonic of the pump frequency measured at the signal port is 30 dB below the power at the pump port.

The conversion loss and the noise figure of the downconverter can be further improved if the stripline signal filter is removed and replaced by a novel waveguide-to-stripline transition [6]. The new transition shows a very small insertion loss at the signal frequency, and the rejection at the image frequency is better than 20 dB. The resulting conversion loss and noise figure for such a converter is improved by approximately 2 dB.

VI. Summary

It is shown that hybrid integrated millimeter-wave downconverters with good noise performance and bandwidth can be built using a stripline circuit and a pair of beam-leaded Schottky-barrier diodes which are pumped at a subharmonic of the conventional local oscillator frequency. The circuit meets the requirements of a digitally modulated system and looks attractive for use in the frequency range from 10 to 100 GHz.

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References

[1] L. C. Tillotson, "Millimeter-wavelength radio systems," *Science*, vol. 170, pp. 31–36, Oct. 2, 1970.
[2] M. V. Schneider and W. W. Snell Jr., "Harmonically pumped stripline down-converter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 271–275, Mar. 1975.
[3] M. Cohn, J. E. Degenford, and B. A. Newman, "Harmonic mixing with antiparallel diode pair," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 667–673, Aug. 1975.
[4] A. Y. Cho and W. C. Ballamy, "GaAs planar technology by molecular beam epitaxy," *J. Appl. Phys.*, vol. 46, pp. 783–785, Feb. 1975.
[5] P. S. Henry, B. S. Glance, and M. V. Schneider, "Reduction of local oscillator noise in the subharmonically pumped downconverter," *IEEE Trans. Microwave Theory and Tech.*, to be published.
[6] T. F. McMaster, M. V. Schneider, and W. W. Snell, Jr., "Millimeter-wave downconverter with subharmonic pump," to be published.

Dielectric Waveguide Microwave Integrated Circuits—An Overview

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Invited Paper

Abstract—**An integrated circuit technique for microwave and millimeter wavelengths which uses refractive-type waveguides and signal processing coupled with planar integration techniques characteristic of microstrip microwave integrated circuits (MIC's) is described. Following a comparison of the optical and millimeter approaches to this circuit technique, a discussion of transmission lines and components for millimeter wavelengths is presented. System applications are also described.**

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I. Introduction

A MICROWAVE integrated circuit (MIC) technique which uses a refractive dielectric waveguide has been emerging for the past several years. Research on this microwave technique has been less extensive than that in the optical dielectric integrated circuit (ODIC) technique. However, practical circuit results and demonstrated system applications have been achieved. A comparison between the microwave and ODIC techniques will be made. Transmission