Letters

Microstrip Varactor-Tuned Millimeter-Wave Transmitter

B. S. GLANCE

Abstract—**A 60-GHz varactor-tuned microstrip oscillator intended for use in a millimeter-wave radio relay experiment has been designed and tested. The output power of the transmitter is 110 ± 15 mW from 58.5 to 60.1 GHz. The oscillator can be frequency-shift keyed (FSK) at a rate up to 200 Mbit/s. The rms FM noise of about 400 Hz/(kHz)$^{1/2}$ meets the required system specifications.**

I. INTRODUCTION

The purpose of this letter is to describe the design and the performance of a 60-GHz oscillator for use as a frequency-shift-keyed (FSK) transmitter in a short hop radio system [1]. The project requires that the oscillator be FSK modulated up to a rate of 200 Mbit/s with an output power of 100 mW. A varactor-tuned IMPATT oscillator has been chosen as the simplest solution fulfilling these requirements. The varactor and the oscillator circuit are both integrated on a quartz substrate on which the conductor patterns are deposited using photolithographic fabrication techniques. The resulting FSK modulator is much less complex and can be produced more easily than comparable waveguide structures.

II. DESCRIPTION OF THE VARACTOR-TUNED OSCILLATOR

The varactor-tuned miscrostrip oscillator which is described in this letter has a circuit configuration similar to a fixed-frequency 60-GHz microstrip oscillator previously reported [2], [3]. The circuit which is shown in Fig. 1 consists of a microstrip conductor pattern on a clear quartz substrate shielded in a rectangular metallic channel and two IMPATT diodes. One of the diodes biased above breakdown generates the output signal. A variable voltage below breakdown is applied to the second diode which acts as a varactor. Fig. 2 shows a more detailed schematic of the metallized circuit which includes two coupled microstrip resonators, each connected to a diode. The two diodes are mounted 0.030 in apart on a cylindrical 0.150-in-diameter stud which is inserted into the channel wall perpendicular to the metallized quartz substrate. A small tab soldered to each microstrip resonator is used to contact the diodes. This structure allows the easy replacement of the diode package without altering the RF circuit. A microstrip network provides dc bias and baseband input to the varactor. It consists of a section of high-impedance microstrip line $\lambda/2$ long, which contacts the varactor resonator near a minimum of electric field. The electrical center of this line is connected to the baseband input line which is terminated by an omnispectra miniature (OSM) connector (not shown in the figures). The dc bias is supplied to the oscillating diode by means of an insulated 0.003-in wire running in a slot along the sidewall of the channel as shown in Fig. 2. The impedance of the bias line jumps from a low value to a high value over the last $\lambda/4$ section before contacting the IMPATT resonator near a minimum of electric field. The dc power is applied through an OSM connector on the back of the sidewall channel (not shown in the figures). The RF output is a 50-Ω microstrip line. One end of the line is capacitively coupled to the oscillator; the other end is used as a transition to a WR 15 waveguide. Radiation losses are suppressed by covering the channel with a metal plate; the channel width is sufficiently small to allow the

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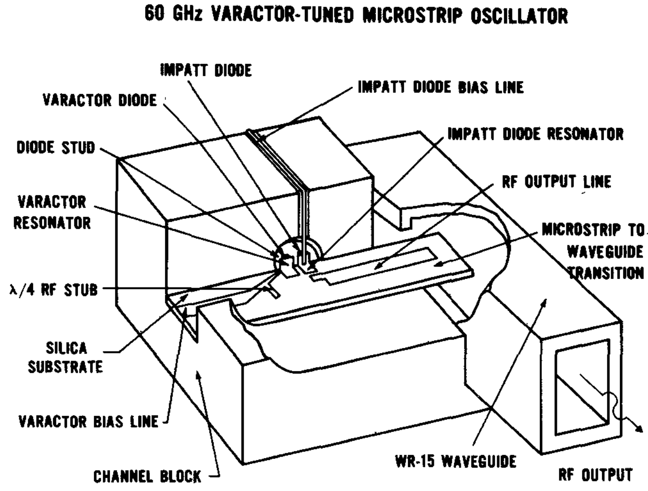

Fig. 1. Varactor-tuned microstrip oscillator assembly.

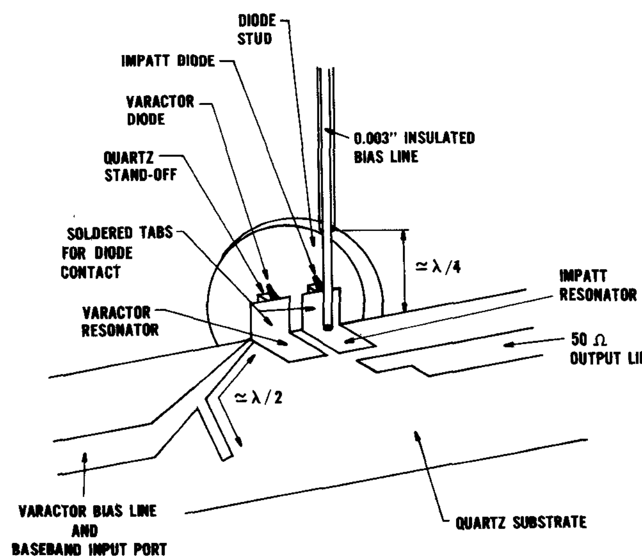

Fig. 2. Microstrip oscillator and varactor circuits on substrate (thickness is 0.010 in, width is 0.080 in).

TABLE I

DIODE AND CIRCUIT PARAMETERS

IMPATT Diode	Double drift Silicon IMPATT diode Diode capacitance at -20 volts is 0.18 pF
Varactor Diode	Double drift Silicon IMPATT diode Diode capacitance at 0 volts is 0.6 pF Diode capacitance at -20 volts is 0.18 pF
Quartz Substrate	Thickness: 0.010" Width : 0.078" Length : 0.800"
Channel	Width : 0.080" Height : 0.050"
Oscillator	Loaded Q = 80 Frequency drift with Temperature ΔF = 3 MHz/°C

propagation of only the microstrip mode. Table I gives diode and circuit parameters.

III. PERFORMANCE OF THE VARACTOR-TUNED OSCILLATOR

Fig. 3 shows the output power of a microstrip varactor-tuned oscillator measured as a function of the varactor voltage. With a bias current of 100 mA an output power of 110 ± 15 mW CW is obtained from 58.5 to 60.1 GHz by changing the varactor voltage from 0 to 25 V. Except for the first few volts, the tuning curve is nearly linear. Wider tuning ranges can be achieved by changing the coupling between the two resonators. However, this reduces the output power and gives larger power variations over the tuning range. A compromise between the tuning range and the output power is achieved by adjusting the coupling between the two resonators with a small piece of ceramic ($\epsilon_r \approx 80$). This minimizes the varactor losses giving a relatively narrow tuning range, but large enough for most radio system applications. The output coupling which is less critical is fixed; its magnitude is determined for maximum output power. The corresponding oscillator Q is about 80.

The output power produced by the tunable oscillator is of the same order as that obtained from a fixed frequency 60-GHz microstrip IMPATT oscillator [2], [3] when biased at the same dc current. Thus the modulator circuit shows no significant loss compared to a fixed frequency microstrip oscillator. FM noise is an important parameter in FSK radio system design. Noise measurements show that the rms FM noise of the varactor-tuned oscillator is about the same as that of the fixed-frequency oscillator [2], [3] about 400 Hz/(kHz)$^{1/2}$. It is sufficiently small not to affect the radio system [4] significantly.

The frequency modulation was measured for different baseband signal shapes. For example, Fig. 4 shows the power spectrum of the output signal when a 50-MHz sinusoidal signal is applied to the varactor. The amplitude of the signal was adjusted to give an index of modulation of about 2.4. Fig. 5 shows a rectangular-pulse-shaped baseband signal which is applied to the varactor for FSK modulation, and the same signal after detection by a FM receiver [3]. Comparison between these two signals shows that the rise time of the rectangular pulses increased by less than 1 ns after being transmitted by the oscillator. This result indicates that the oscillator can sustain a modulation rate of up to 200 Mbit/s.

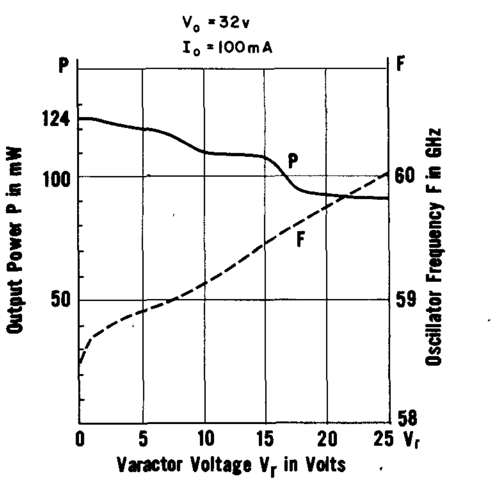

Fig. 3. Output power and frequency of the varactor-tuned microstrip oscillator as a function of the varactor voltage.

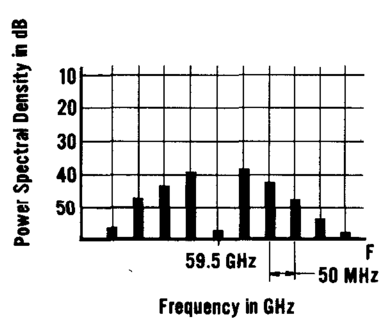

Fig. 4. Power spectrum of the output signal at 59.5 GHz with a sinusoidal signal applied to the varactor to give an index of modulation of 2.4 at a rate of 50 MHz.

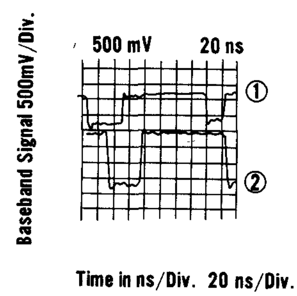

Fig. 5. This figure shows a rectangular pulse-shaped baseband signal applied to the varactor for FSK modulation and the same signal after detection by a FM receiver. The rise time of the input signal is 1.5 ns.

IV. SUMMARY

A hybrid integrated microstrip varactor-tuned oscillator has been built at 60 GHz giving about 100 mW over a 1.6-GHz frequency range. The device can be used as an FM or FSK radio transmitter sustaining modulation rates up to 200 Mbit/s. These results have been obtained with a simple diode package made of two IMPATT diodes, one used as a regular IMPATT oscillating diode, the other one as a varactor for frequency tuning.

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Asymmetric Odd-Mode Fringing Capacitances

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Abstract—**An expression is given for the odd-mode fringing capacity of an infinite rectangular bar asymmetrically located inside an infinite U-shaped outer conductor.**

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