A Compact 60-GHz Transmitter–Receiver

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***Abstract*—A new, compact, low-cost, and reliable 60-GHz transmitter–receiver was developed for civilian use. Common components are used for transmitting and receiving functions. An IMPATT oscillator generates the millimeter-wave output power for both the transmitter and the receiver local oscillator. A common antenna is also used for transmitting and receiving signals without a circulator. A mixer is used as a modulator in transmission as well as a receiver front end. A noise figure of 13 dB is obtained by a balanced mixer with a 200-MHz IF frequency differential preamplifier. A reliable packaged GaAs varactor diode is used for the mixer–modulator (MM).**

Introduction

CONSIDERABLE progress in millimeter-wave components has been made recently. Systems for high-capacity millimeter-wave transmission through a low-loss waveguide are being constructed [1], [2]. Besides these high-capacity transmission systems, many millimeter-wave systems with smaller capacity are envisioned for civilian use. For example, automotive radars [3] or short-range transmitter–receivers (transceivers) which can take advantage of the sharpness of the beam with a small size antenna and of interference-free operation with established microwave systems will be extensively used if low cost and high reliability in outdoor environments are achieved.

This paper describes an experimental 60-GHz transceiver for use in an automobile control system. Transceivers are mounted on gates constructed over a highway. Two-way digital communication is made with cars equipped with the transceiver when the car passes under the gate. Video information for root guidance, traffic control, and other services is communicated between the car and road-side terminal followed with a central computer.

A new configuration is presented in which components such as the antenna, the IMPATT oscillator, and the mixer–modulator (MM) are used for both transmitting and receiving. Low noise performance is obtained by using a balanced mixer configuration. Design considerations, characteristics of the components, and performance of the transceiver are described.

System Design Considerations

The 60-GHz carrier band was selected for the following reasons. At this frequency band, the absorption by atmospheric oxygen molecules is fairly high. A narrow beam can be formed with a relatively small antenna. Thus efficient frequency reuse over small areas, as well as sufficient isolation from other communication systems, is possible.

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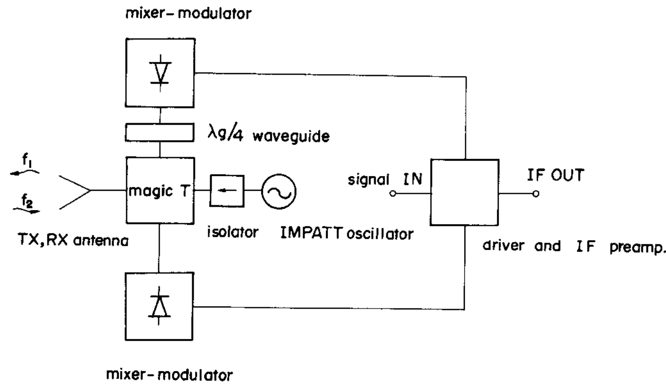

Fig. 1. Transmitter–receiver block diagram.

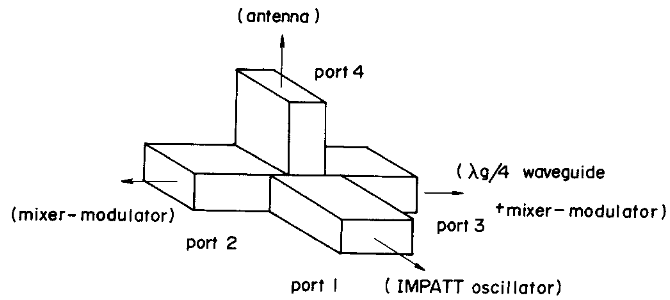

Fig. 2. Magic T illustration and connection at ports.

In order to use only one oscillator as the output power source for transmitter operation and as the local oscillator for receiver operation, two types of transceivers are developed the carrier frequencies of which differ by the IF frequencies 60.0 and 60.2 GHz. The two transceivers are used in pairs resulting in an IF frequency of 200 MHz. The IMPATT oscillator used in the receiver imposes design problems such as high noise level and frequency drift due to temperature variation. The frequency drift problem is solved by using amplitude–modulation of the millimeter wave with a stable subcarrier. The noise problem is solved by the adoption of a balanced mixer. The intermediate frequency of 200 MHz is chosen high enough to allow for an IF amplifier bandwidth of ± 60 MHz, required by the frequency drift of the IMPATT oscillator.

A block diagram of the transceiver system is shown in Fig. 1. Connection to the magic T is shown in Fig. 2. Port 1 is connected to the IMPATT oscillator, port 2 to the MM, port 3 to a quarter-wavelength waveguide followed by the MM, and port 4 to the antenna. The two MM's are a matched pair. Connection at ports 1 and 4 can be interchanged in operation.

In operation as a transmitter, the bias voltage for the modulators (MM) is switched between two states by a subcarrier. One state (state A) of the bias voltage is selected to match the impedance of the MM's for the IMPATT output wave. No wave emerges from port 4 to the antenna in this case. The other state (state B) is selected to reflect most of the IMPATT output wave. The reflected waves are equal in amplitude and opposite in phase at ports 2 and 3, due to the 180° phase shift introduced by two passes through the quarter-wavelength waveguide, and therefore, emerge from port 4, as is seen from the characteristic of the magic T. Thus an amplitude-modulated millimeter wave is transmitted through the antenna.

In operation as a receiver, bias voltages for the MM's are set at state A. The IMPATT oscillator generates a millimeter wave at frequency f_1, and acts as a local oscillator for the mixers (MM). The receiving signal of frequency f_2, fed to port 4 through the antenna, is mixed with the local oscillator, and the IF signal of frequency $f_1 - f_2$ is obtained. The quarter-wavelength waveguide has no effect on the IF signal because both the input signal and the local oscillator wave are phase shifted by 90° and because the phase of the IF signal is the difference between the signal and local oscillator phases. The two IF signal phases are opposite from each other, due to the phase shift in the magic T. These signals can be combined by means of a center-tapped transformer or a differential amplifier. The latter is adopted in the present case because it is easier to adjust.

The IMPATT oscillator noise converted into the IF band, which may be at a high level, can be canceled at this differential amplifier since the IF noises have the same phase.

As is seen from the operation explained previously, communication between two transceivers can be made only one way at a time, i.e., only simplex communication is possible.

Components Design

IMPATT Oscillator: A silicon DDR IMPATT oscillator, stabilized with a transmission cavity, is adopted. Output power is around 7 mW. The output power and frequency deviation are within ±1 dB and ±30 MHz, respectively, in the −15–+55°C temperature range. DC to millimeter-wave efficiency is about 0.2 percent with the stabilized cavity.

Mixer-Modulator: The MM is the key device for the present system. A packaged GaAs Schottky varactor diode V101 (Nippon Electric Company, Ltd.) developed for use in a parametric amplifier, pumped at 60 GHz, is used. Characteristics of the diode are shown in Table I. This diode, having an extremely high cutoff frequency, exhibits excellent performance as both mixer and modulator.

The typical return loss of the MM versus dc bias voltage is shown in Fig. 3. It is shown that a return loss of more than 20 dB at state A and less than 2.5 dB at state B can be obtained. These results correspond to amplitude-modulated output losses of the same values.

The return loss at state A is very sensitive to the bias voltage. In fact, the return loss deteriorates considerably with temperature variation when the bias voltage is kept constant. A small-signal analysis and experiment indicate that the condition for minimum variation in diode RF impedance is equivalent to constant dc current. A temperature-compensated constant dc current source is, therefore, adopted for the driver of state A. A return loss of more than 25 dB was obtained over the −20–+50°C temperature range for a power input of 7 dBm with a driver which will be described later.

TABLE I
GaAs Varactor Diode V101 Characteristics

Cut Off Frequency (f_c)	f_c(0V) ≧ 600GHz, f_c(-6V) ≧ 1200GHz
Barrier Capacitance (C_b)	C_b(0V) = 0.5∿0.15pF
Dynamic Q ($\tilde{Q}$)	$\tilde{Q}$(4GHz) ≧ 35
Series Resistance (R_s)	R_s < 1Ω
Junction Diameter (D)	D ≈ 12μm

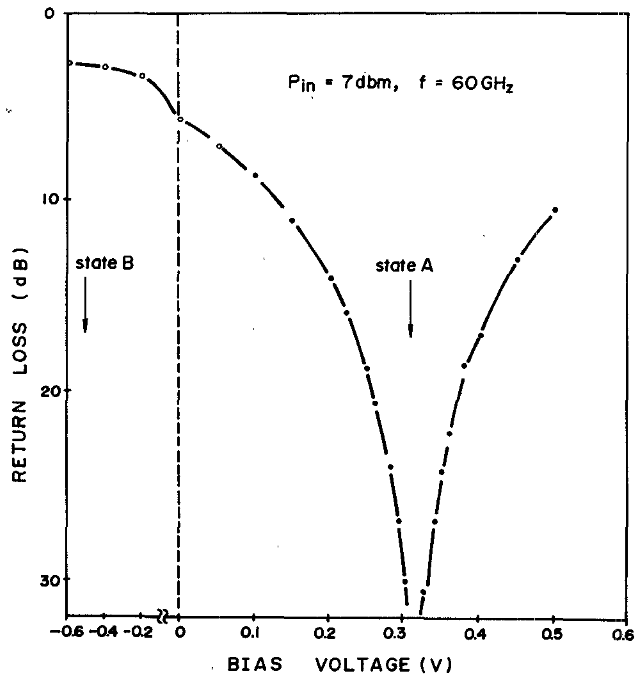

Fig. 3. Return loss versus dc bias voltage for a MM.

Diode V101 offers a very low conversion loss, such as 5 dB, which is comparable to those with a wafer-type diode [5]. A packaged diode is easier to use compared with a wafer-type diode. Conversion loss versus local oscillator power is shown in Fig. 4 for optimum bias voltages. The optimum bias currents for high return loss and low conversion loss are quite close and, therefore, the bias current for the MM operating as a mixer is chosen to be the same as the one for modulator state A.

Driver and IF Preamplifier: The driver and the IF preamplifier are installed in the same package. Fig. 5 shows a block diagram of the driver and IF preamplifier. The driver switches the bias states (state A, B) for the MM's corresponding to the amplitude-modulating input signal. The rise time of the driver is less than 10 ns. The driver operates as a temperature-compensated constant current source for state A and as a constant voltage source for state B. Since the driving signals enter the MM's in phase, the leaked signals are canceled at the differential preamplifier and have no effect on the amplifier.

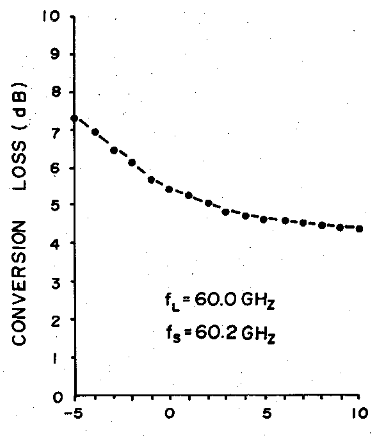

Fig. 4. Conversion loss versus dc bias voltage for a packaged diode mixer as a function of local oscillator power input.

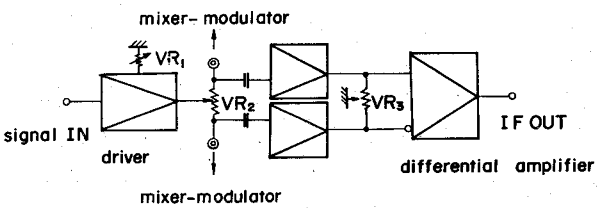

Fig. 5. Driver and differential IF preamplifier block diagram.

The currents for the two MM's can be adjusted by variable resistors VR1 and VR2 to adjust for the unbalanced characteristic of the two millimeter diodes.

The measured noise figure and the gain of the IF preamplifier are 4.5 and 30 dB, respectively. The phase and magnitude of the noise to be canceled at the differential preamplifier are controlled by lengths of the cables between the MM's and the amplifier, and by variable resistor VR_3, respectively.

Transceiver Performance

The detected signals of the transmitter output for 10- and 20-MHz rates are shown in Fig. 6. The millimeter-wave peak power output is 4 mW. The ON–OFF ratio is more than 20 dB over the −10–+50°C temperature range.

The noise figures measured by the signal generator method with an IF filter with 13.5-MHz bandwidth are shown in Fig. 7 as a function of the local oscillator power. The solid line shows the case of noise cancellation and the dotted line shows the case when noise cancellation is not made. The noise figure is improved by about 20 dB by the noise cancellation. Noise figures with a klystron local oscillator instead of the IMPATT oscillator are also shown in Fig. 7 for comparison purposes.

An internal view of the transceiver is shown in Fig. 8. The size is about 250 × 150 × 100 mm and weight is 4 kg. The enclosure is water proofed. The output waveguide is hermetically sealed.

With this transceiver, more than 300 kbits of information can be communicated with a sufficient signal-to-noise ratio margin between the car and the gate, assuming a car speed

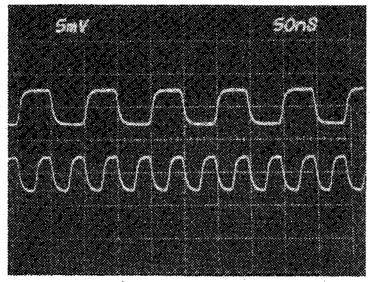

Fig. 6. Detected transmitter output signal. Horizontal scale is 50 ns/div.

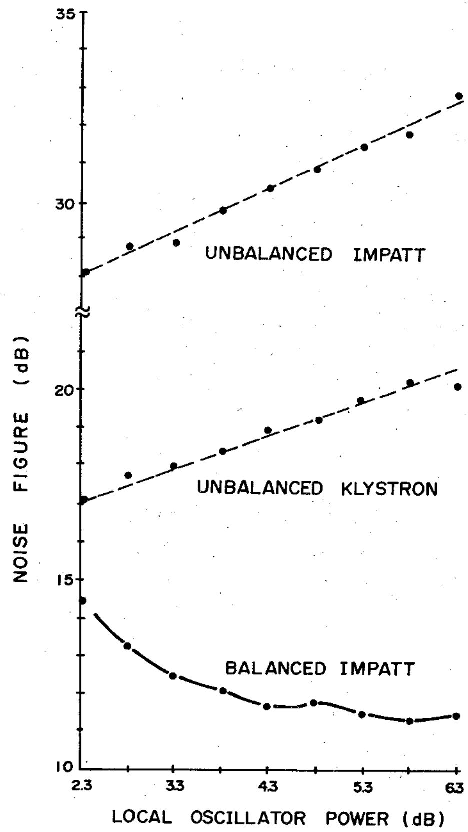

Fig. 7. Noise figure as a function of local oscillator power.

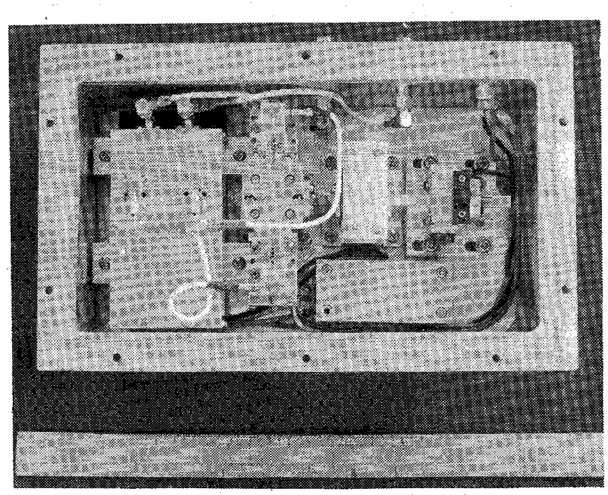

Fig. 8. Internal transmitter–receiver view.

of 80 km/h, a communication area length of 2 m, antenna gain of 15 dB and a gate height of 5 m. As another example, a signal-to-noise ratio of 35 dB with a signal bandwidth of 1 MHz can be obtained at a distance of 100 m with an antenna of 20 dB gain.

Conclusion

The new configuration can make a transceiver very compact. The used packaged millimeter-wave diode and the minimal component count would contribute to the increase of reliability. Adjustment is easily made to balance the MM. This type of transceiver can be used for a variety of millimeter-wave systems for civilian use.

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A *V*-Band Communication Transmitter and Receiver System Using Dielectric Waveguide Integrated Circuits

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***Abstract*—A *V*-band communication transmitter and receiver is described. Both units make extensive use of passive microwave components fabricated using millimeter-wave insular line integrated circuits (MILIC's). These components consist of rectangular dielectric rod antennas, a MILIC ferrite isolator, a bandpass ring filter, a directional coupler, and sections of dielectric insular waveguide. The passive insular waveguide components are integrated together, along with split block metal waveguide mounts for the active devices, in order to form the RF circuitry of the transmitter and receiver.**

I. Introduction

THIS PAPER describes a short-range one-way *V*-band communication system. The system consists of a separate transmitter and receiver module complete with all oscillator, mixer, modulation, biasing, and IF circuitry necessary for its operation. Millimeter-wave insular line integrated circuits (MILIC's) [1], [2] were extensively used for the passive microwave components in the RF sections of each unit.

The transmitter and receiver modules, which will be described, are the end product of a developmental effort of dielectric insular waveguide and associated components [3], [4]. The projected advantages of the MILIC's include: low production costs, high reliability, compact size, and applicability to system work in the *V* band and above. The dielectric insular line components which were developed and integrated together to form the complete system include: rectangular dielectric rod antennas, a MILIC ferrite isolator, a bandpass ring filter, a mode transition, and a directional coupler. In addition, an IMPATT oscillator, a Gunn oscillator, and a mixer were developed in standard waveguide and integrated with the MILIC components, using appropriate transitions.

II. Transmitter Module Layout

The transmitter module consists of a series of insular dielectric waveguide components and rectangular metal waveguide devices integrated together to form a complete package. The major RF components of the transmitter are: 1) a dielectric rod antenna, 2) a MILIC ferrite isolator,

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