Uniplanar MIC Balanced Multiplier— A Proposed New Structure for MIC's

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Abstract —**A novel uniplanar MIC (microwave integrated circuit) and a balanced MIC multiplier are proposed and their characteristics discussed. The circuits use a combination of coplanar waveguides, slotlines, and bonding wires on one side of the substrate. A uniplanar MIC multiplier is designed for use in the 13- and 26-GHz bands and fabricated on an alumina substrate. Good performance with respect to isolation between RF ports is achieved.**

I. Introduction

Microwave integrated circuits (MIC's) have been successfully used in developing a number of microwave components [1]. Microstrip lines have been used as the main transmission line. However, coplanar waveguides and slotlines, as well as finlines, have recently been utilized for microwave circuits [2]. In addition to the use of these transmission lines, a structure with a combination of microstrip lines and slotlines, called a double-sided MIC, has been proposed. Many functional circuits which are difficult to fabricate with conventional microstrip techniques have been developed [3]–[5].

This paper proposes "uniplanar" circuit configurations[1] for MIC's. The uniplanar MIC does not use the back side of the substrate. However, it has the same functions as the double-sided MIC and has the potential for application to the monolithic MIC (MMIC) structure [6]. In addition, the circuit fabrication process of the uniplanar MIC is simpler than that of the double-sided MIC, because only one side of the substrate is used. Features of the uniplanar MIC are summarized as follows:

1) The fundamental components are coplanar waveguides, slotlines, and bonding wires.
2) A bonding wire connects a coplanar waveguide with a slotline. The deterioration of the insertion loss and return loss due to bonding wires is very small and does not affect the circuit performance of uniplanar circuits.
3) No through-holes are needed to connect active devices with the ground conductor because of the line structure of the coplanar waveguides and slotlines.

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[1]Since the circuit utilizes only one substrate surface, it will be called a uniplanar circuit.

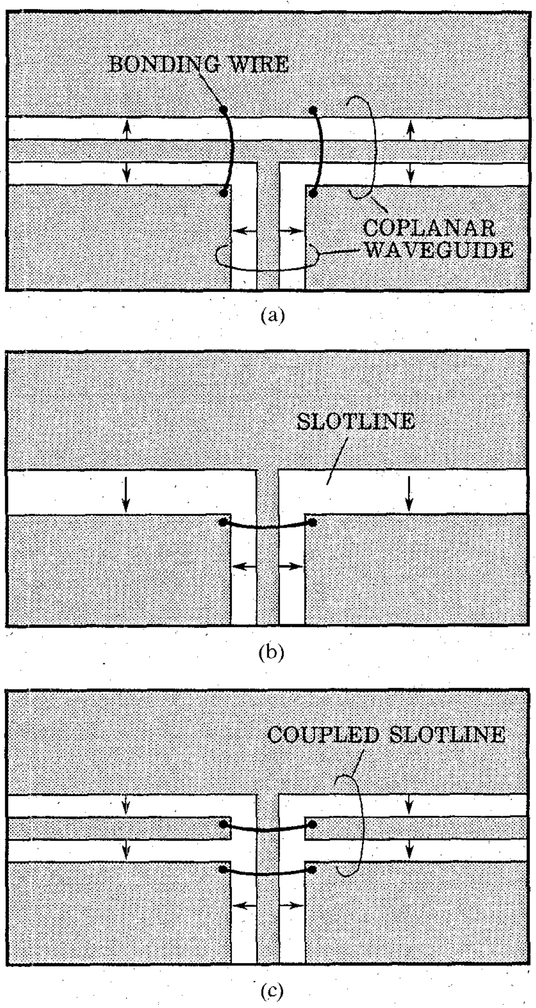

Fig. 1. Uniplanar MIC T junctions (I). (a) Coplanar waveguide T junction. (b) Coplanar waveguide/slotline junction. (c) Coplanar waveguide/coupled slotline junction.

4) Both the series and parallel T junctions are fabricated by the combination of fundamental components.
5) The performance of uniplanar circuits can be adjusted by changing the position of bonding wires; e.g., the load termination condition for devices can be optimized by changing the lengths between devices and bonding wires.

This paper first discusses the fundamental circuit configurations of uniplanar MIC's, i.e., the series and parallel T junctions, and the transition circuits from coplanar wave-

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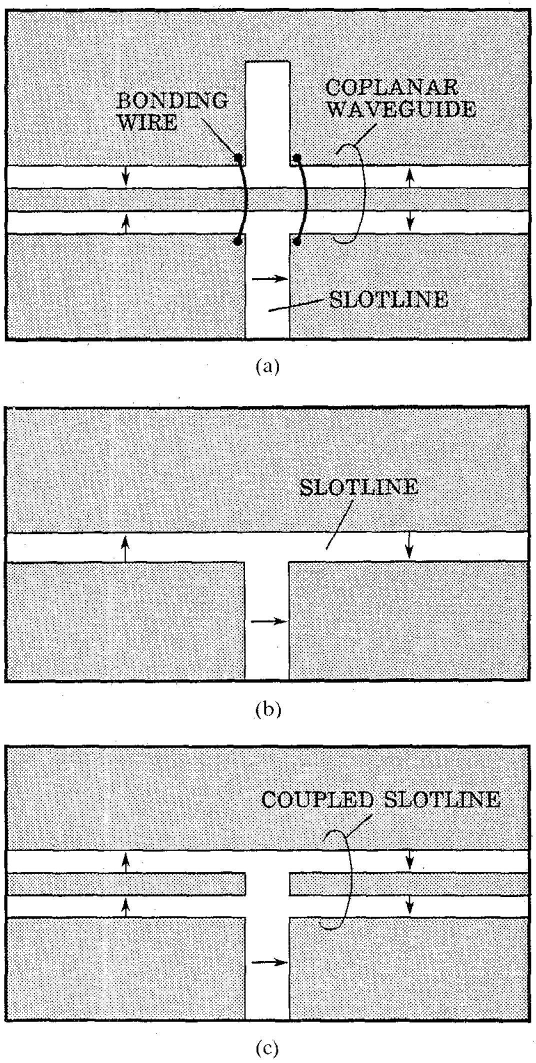

Fig. 2. Uniplanar MIC T junctions (II). (a) Slotline/coplanar waveguide junction. (b) Slotline T junction. (c) Slotline/coupled slotline junction.

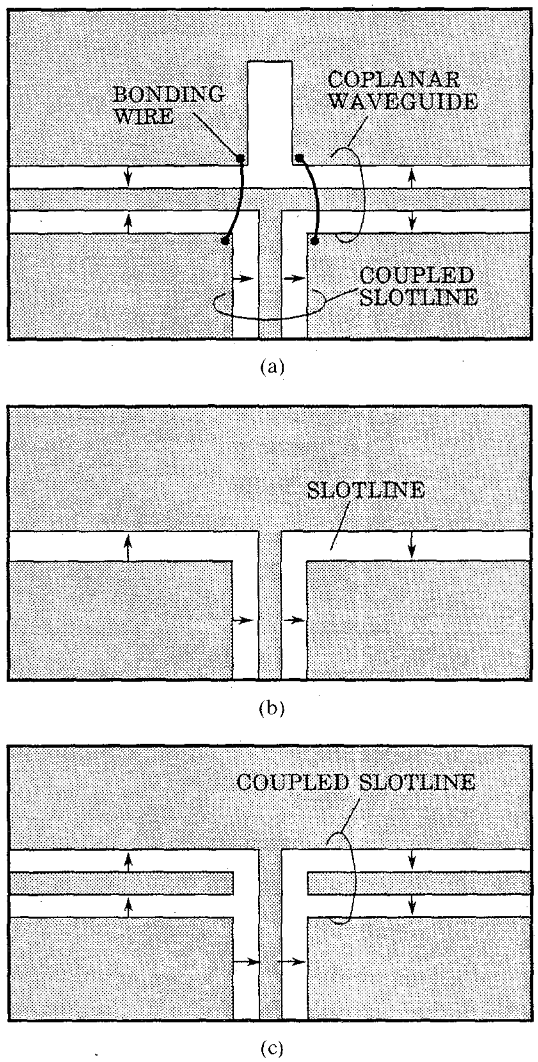

Fig. 3. Uniplanar MIC T junctions (III). (a) Coupled slotline/coplanar waveguide junction. (b) Coupled slotline/slotline junction. (c) Coupled slotline T junction.

guides to slotlines or vice versa. A balanced multiplier which utilizes the advantages of the uniplanar MIC is then proposed and designed for use in the 13-GHz and 26-GHz bands. These multipliers show good performance and will be expected to play an important part in microwave radio equipment.

II. Uniplanar MIC

As mentioned above, the most fundamental components of the uniplanar circuits are coplanar waveguides, slotlines, and bonding wires. The structure of the coupled slotline is similar to that of the coplanar waveguide. However, the coupled slotline has two orthogonal modes [7], and its even-mode field distribution is different from that of the odd mode. Basic T junctions for the uniplanar MIC are classified according to the combination of transmission lines, i.e., coplanar waveguide, slotline, and coupled slotline. The circuit configurations of the uniplanar T junctions are illustrated in Figs. 1–3, and Table I classifies the parallel and series T junctions in accordance with the input and output transmission lines. The parallel T junctions require the unbalanced line as an input transmission line, while the series T junctions require the balanced line. In Fig. 1(a), two bonding wires are connected to allow current flow and equalize the potential of outer conductors. The T junctions which do not need wire bondings are also depicted in Figs. 2 and 3. These circuits are included in the uniplanar MIC concept. Both parallel and series T junctions can be fabricated using only one side of the substrate. This makes it possible to construct such microwave

TABLE I
Classification of Uniplanar MIC T Junctions

Input Transmission Lines \ Output Transmission Lines	Coplanar Waveguide	Slotline	Coupled Slotline (for even mode)
Coplanar Waveguide	Parallel (Fig. 1 (a))	Parallel (Fig. 1 (b))	Parallel (Fig. 1 (c))
Slotline	Series (Fig. 2 (a))	Series* (Fig. 2 (b))	Series* (Fig. 2 (c))
Coupled Slotline (for even mode)	Series (Fig. 3 (a))	Series* (Fig. 3 (b))	Series* (Fig. 3 (c))

*Although the structures do not require bonding wires, these T junctions are necessary for realizing uniplanar MIC's.

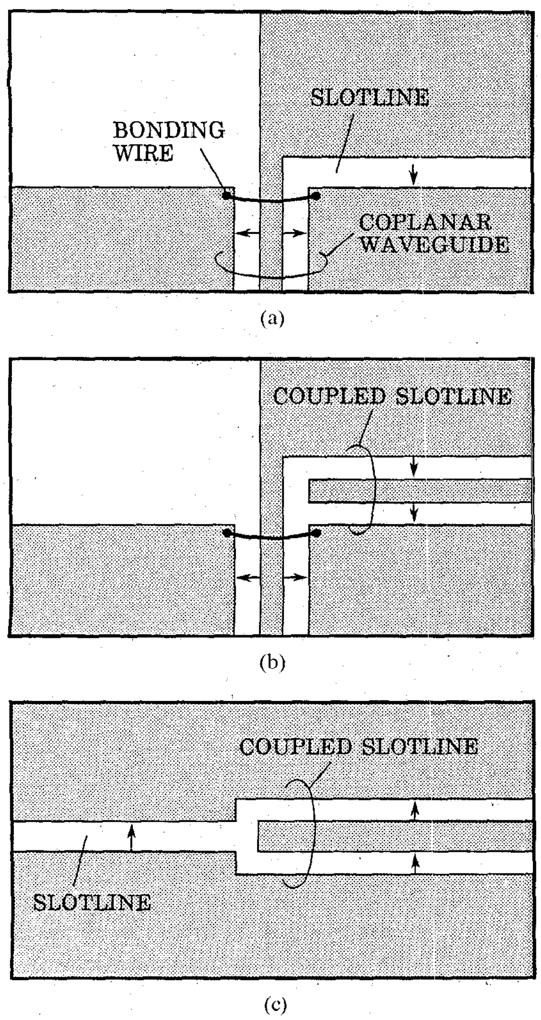

Fig. 4. Uniplanar MIC transition circuits. (a) Coplanar waveguide/slotline transition. (b) Coplanar waveguide/coupled slotline transition. (c) Slotline/coupled slotline transition.

TABLE II
CLASSIFICATION OF UNIPLANAR MIC TRANSITIONS

Input Transmission Lines \ Output Transmission Lines	Coplanar Waveguide	Slotline	Coupled Slotline (for even mode)
Coplanar Waveguide	—	Fig. 4 (a): Modification of coplanar waveguide/slotline junction (Fig. 1(b))	Fig. 4 (b): Modification of coplanar waveguide/coupled slotline junction (Fig. 1(c))
Slotline	Fig. 4 (a)	—	Fig. 4 (c): Modification of slotline/coupled slotline junction (Fig. 2(c))
Coupled Slotline (for even mode)	Fig. 4 (b)	Fig. 4 (c)	—

functional components as hybrid circuits and balanced circuits [8].

The other basic components for the uniplanar MIC are the transition circuits from the coplanar waveguide to the slotline or vice versa. The circuit configuration is shown in Fig. 4, and Table II summarizes the input and output transmission lines of the transition circuits. The coplanar waveguide/slotline transition circuit is made by modifying the coplanar waveguide/slotline junction. The other transition circuits are also fabricated using combinations of slotline and coupled slotline. In Figs. 4(a) and (b), the

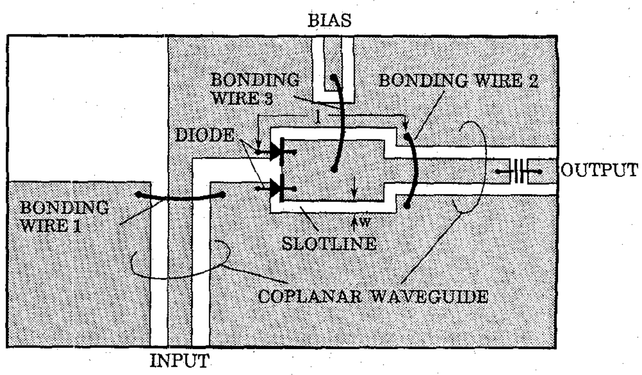

Fig. 5. Circuit configuration of uniplanar MIC balanced multiplier.

open circuits and bonding wires are used to make a perfect matching between coplanar waveguides and slotlines. While the current on the center conductor of coplanar waveguides flows into one of the ground conductors of the slotlines, the backward current on the outer conductors of the coplanar waveguides flows from the other conductors of the slotlines through a bonding wire. In this transition process, the electromagnetic field distributed in two slots of the coplanar waveguides is concentrated into one slot by use of a bonding wire and an open circuit; i.e., the coplanar waveguide mode is transformed to the slotline mode.

III. UNIPLANAR BALANCED MULTIPLIER

A new circuit configuration for a balanced multiplier is proposed using the uniplanar MIC technique described above. The circuit configuration of the multiplier is shown in Fig. 5. The coplanar waveguide/slotline junction and the coplanar waveguide/slotline transition circuit are successfully utilized to produce the balanced circuit. Bonding wire 1 is used to transform the coplanar waveguide mode to the slotline mode. The input signal and the odd harmonics do not couple with the output coplanar waveguide due to bonding wire 2, because the parallel coplanar waveguide/slotline junction can only combine the in-phase signals which propagate on slotlines. The bias voltage is supplied to diodes through bonding wire 3. The isolation between dc and RF is achieved by the high inductance of bonding wire 3, whose value depends on the wire length. All components required for constructing the balanced multiplier are fabricated on one side of the substrate. The slotline length between the diode and bonding wire 2 is selected to be a quarter wavelength at the input frequency to satisfy the open termination condition for diodes at the input frequency.

The equivalent circuit of the multiplier is shown in Fig. 6. The balanced/unbalanced transition circuit plays an important role in the multiplier [9], [10], because BPF and BRF, which make the circuit size large, can be eliminated. The input power is supplied to two diodes out of phase. Arrows represent the direction of the applied voltage or generated harmonics voltages. Since the second harmonics and higher even harmonics are generated by the two diodes in phase, these harmonics can be obtained from the output port. On the other hand, odd harmonics as well as

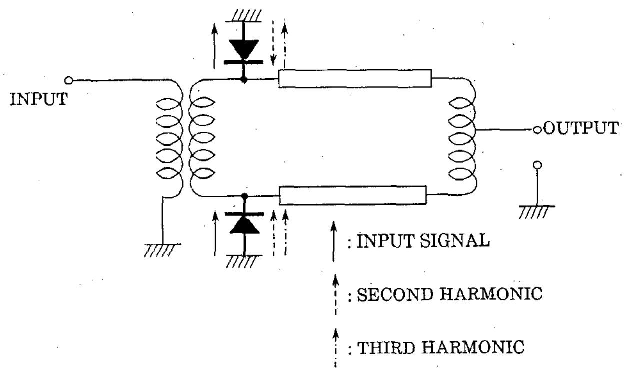

Fig. 6. Equivalent circuit of uniplanar MIC balanced multiplier.

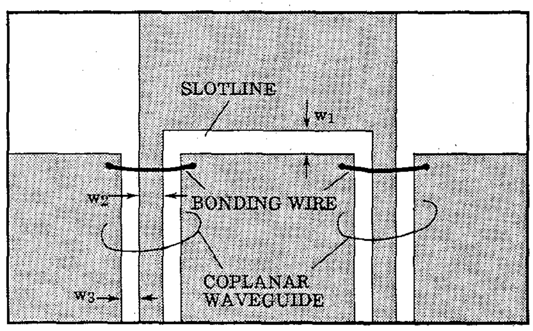

Fig. 7. Circuit configuration of coplanar waveguide/slotline transition.

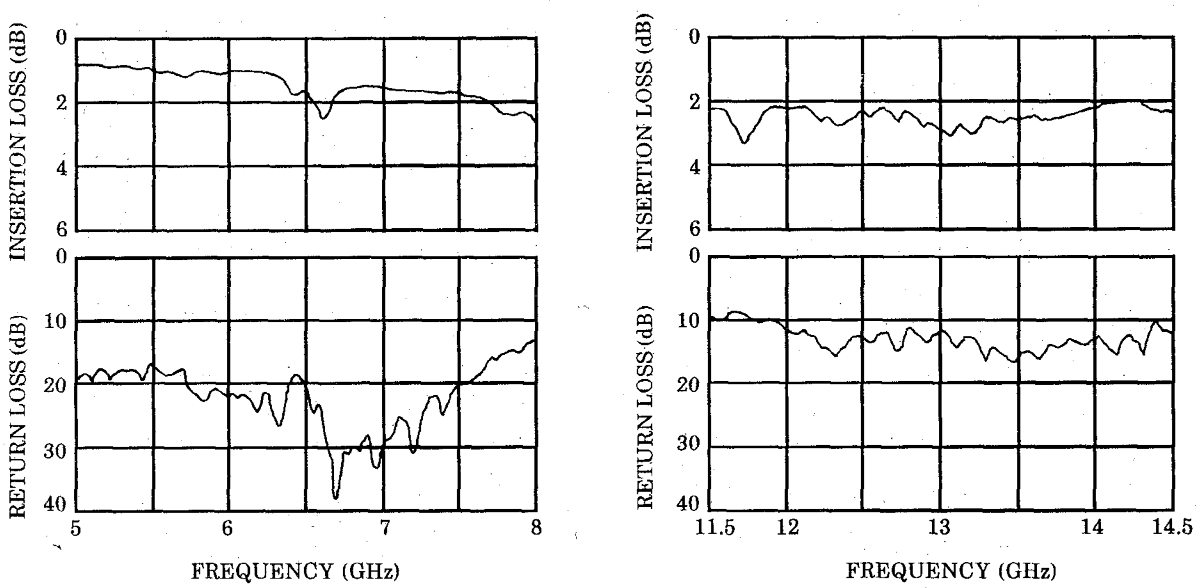

Fig. 8. Frequency response of coplanar waveguide/slotline transition ($w_1 = 0.1$ mm, $w_2 = 0.3$ mm, $w_3 = 0.15$ mm).

the input signal propagate along the slotline out of phase, and these are short-circuited at the junction of the slotlines and the coplanar waveguide. All odd harmonics are reflected and decoupled to the output port. Thus the balanced multiplier fabricated on one side of the substrate can be built using the uniplanar MIC technique.

IV. Experimental Results

A. Coplanar Waveguide/Slotline Transition

To confirm the behavior of the fundamental components of the uniplanar MIC, the coplanar waveguide/slotline transitions were fabricated by the usual photolithographic technique on an alumina substrate. Fig. 7 shows the circuit pattern of the transitions. After electroplating, the two ground conductors of the coplanar waveguide were connected by bonding wires.

The frequency response of the transition is shown in Fig. 8. The insertion loss includes the transmission loss of two coaxial connectors and two coplanar waveguide/slotline transitions, and the conduction loss of the slotline (15 mm) and the coplanar waveguide (14 mm). The intrinsic loss of the transition was estimated to be less than 0.5 dB after eliminating the above excess losses. These results show that the use of bonding wire structures does not interfere with the circuit performance and may allow development of various uniplanar circuits.

B. Balanced Multiplier

The circuit shown in Fig. 5 was fabricated on an alumina substrate and designed for use in the 13- and 26-GHz bands. Two beam-lead Schottky-barrier diodes were used in the multiplier. The conversion loss versus the input power is shown in Fig. 9. The input frequencies are fixed at 6.5 GHz and 13 GHz. As the forward bias voltage to the diodes increases, the minimum conversion loss can be obtained at a lower input power. In Fig. 9(a), the minimum conversion loss is 9.8 dB at an input power of 21.5 dBm and a forward bias voltage of 0 V. In the 26-GHz-band multiplier, the minimum conversion loss is 11.1 dB at an input power of 19 dBm.

The balanced circuit has the following advantages: high isolation between the input and output ports is obtained, and even harmonics can couple with the output port, while odd harmonics cannot. The isolation characteristics be-

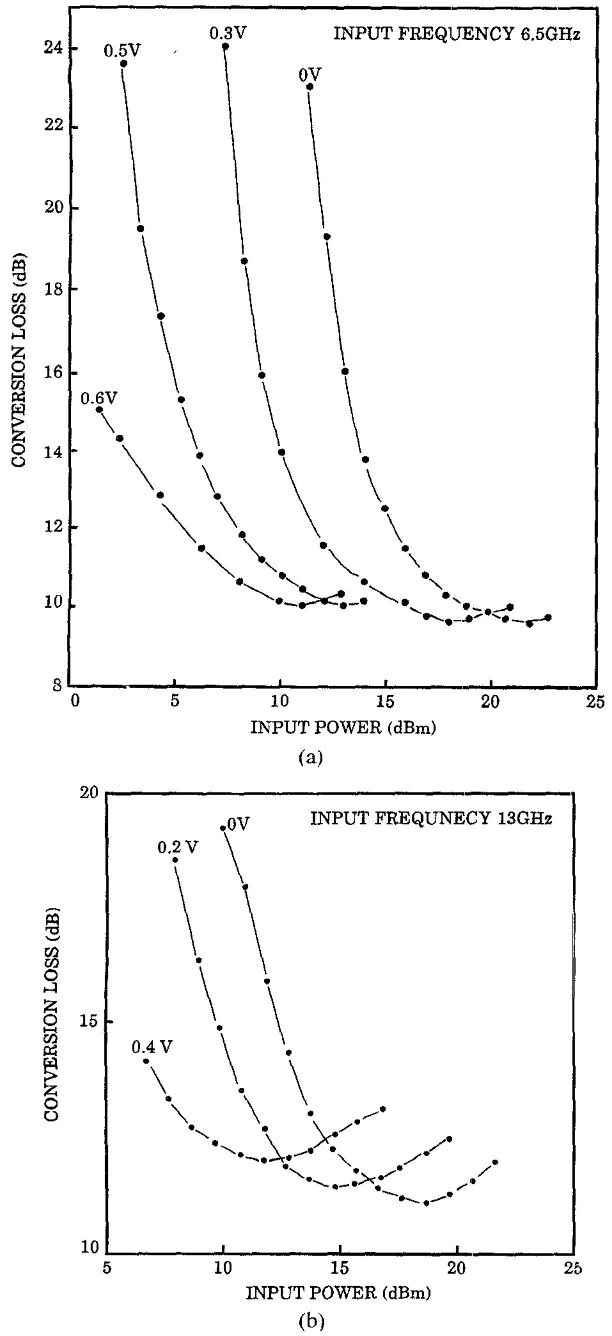

Fig. 9. Conversion loss of balanced multiplier ($w = 0.4$ mm, $l = 6.329$ mm). (a) Input frequency is 6.5 GHz. (b) Input frequency is 13 GHz.

tween the input and output ports are shown in Fig. 10. The isolation is greater than 23.5 dB. The return loss at the input port is also shown in Fig. 10. The return loss becomes worse as the input power decreases, because the diode impedance depends on the input power. The diode impedance increases as the input power decreases; therefore the reflection of the input power increases. On the other hand, the diode impedance becomes smaller as the input power becomes larger, so the return loss becomes larger, as shown in Fig. 10. Fig. 11 shows the isolation characteristics of the 26-GHz-band multiplier. As seen from these figures, a balanced multiplier with high isolation has been achieved using the uniplanar MIC technique.

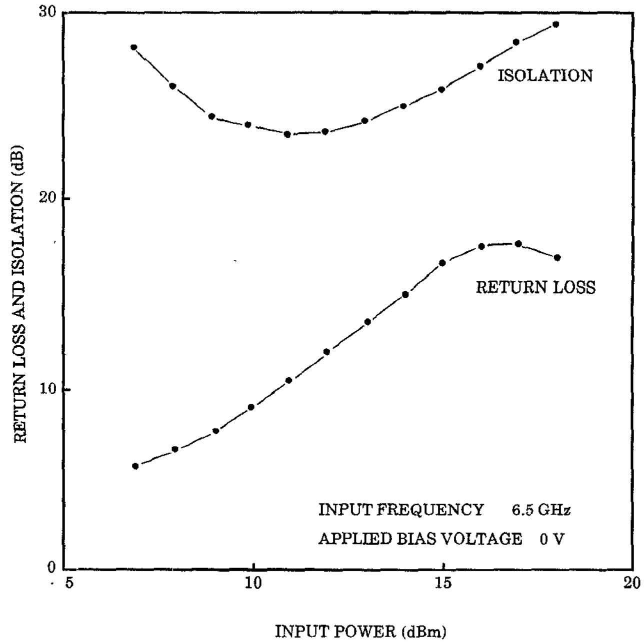

Fig. 10. Isolation and return loss of 13-GHz-band balanced multiplier. Input frequency is 6.5 GHz and applied bias voltage is 0 V.

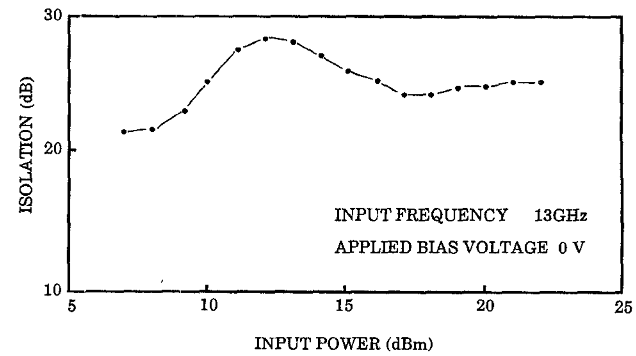

Fig. 11. Isolation of 26-GHz-band balanced multiplier. Input frequency is 13 GHz and applied bias voltage is 0 V.

V. Conclusions

A novel uniplanar MIC and a balanced MIC multiplier have been proposed. They use coplanar waveguides, slotlines, and bonding wires on one side of the substrate. The fundamental components of the uniplanar MIC's, e.g., the coplanar waveguide/slotline transition, have been fabricated and tested. Experimental results showed that the use of bonding wire structures allows the development of various uniplanar circuits. A balanced multiplier has also been fabricated and good performance was achieved. In particular, high isolation between the input and output ports has been obtained. This uniplanar MIC technique is promising for applications in such microwave circuits as modulators, frequency converters, and amplifiers.

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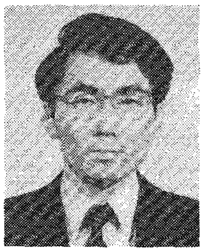

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