Short Papers

A New Uniplanar Broad-Band Singly Balanced Diode Mixer

Pang-Cheng Hsu, Cam Nguyen, and Mark Kintis

***Abstract*— A new type of completely uniplanar broad-band singly balanced diode mixer, which utilizes a coplanar waveguide (CPW) and slot line as the main transmission lines, is presented. With the radio frequency (RF) swept from 7.1 to 10.5 GHz and the local oscillator (LO) of 3.5 dBm at 7 GHz, the mixer exhibits a conversion loss from 6 to 10 dB. The LO-to-RF isolation is better than 20 dB, and the LO-to-intermediate frequency (IF) and RF-to-IF isolations are more than 36 dB. The mixer also exhibits good return loses at all three ports. It has several desirable features such as simplicity, wide bandwidth, good interport isolations, easy mounting of solid-state devices, and no via-hole ground connections. The uniplanar nature of this mixer makes it very suitable for low-cost microwave and millimeter-wave integrated circuits.**

***Index Terms*— Microwave integrated circuits, microwave monolithic integrated circuit, mixer, uniplanar circuit.**

I. Introduction

It has been recognized that uniplanar structures, in which all of the circuit elements are located on the same substrate side, are very desirable for low-cost and simple microwave integrated circuits (MIC's) and microwave monolithic integrated circuits (MMIC's). This is primarily due to the facts that solid-state devices can be easily mounted, via holes connecting circuit elements to the ground are not needed, and circuit processing becomes simpler. Many efforts have been concentrated in developing uniplanar MIC's and MMIC's [1], [2].

In this paper, we report on the development of a new uniplanar singly balanced diode mixer employing a coplanar waveguide (CPW) and slot line. This new mixer is completely uniplanar and employs novel wide-band compact CPW-to-slotline transition and a hybrid junction. The hybrid junction especially exploits a unique combination of the slot line and CPW's field distributions to create a small frequency-independent structure. Matching from the local oscillator (LO), intermediate frequency (IF), and radio frequency (RF) ports to the diodes is also very easy in this mixer because the diodes appear in parallel and series from the LO/IF and RF ports, respectively. Altogether, these features produce a compact balanced mixer with a good conversion loss and high interport isolations over a wide bandwidth. With the first-iteration design, a conversion loss of 6–10 dB has been measured over 7.1–10.5-GHz RF bandwidth with only 3.5-dBm LO power at 7 GHz. More than 20-dB LO-to-RF isolation and better than 36-dB RF-to-IF and LO-to-IF isolations have also been observed. Moreover, good return losses have been achieved at all three ports.

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P.-C. Hsu and C. Nguyen are with the Department of Electrical Engineering, Texas A&M University, College Station, TX 77843-3128 USA.

M. Kintis is with TRW Electronics Systems & Technology Division, Redondo Beach, CA 90278 USA.

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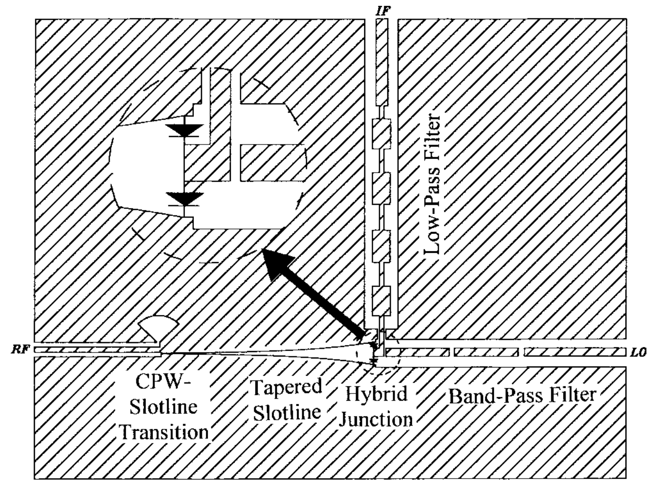

Fig. 1. Layout of the uniplanar singly balanced diode mixer.

II. Circuit Design

Fig. 1 shows a circuit layout of the newly developed uniplanar singly balanced diode mixer. The central portion of the circuit is enlarged to show the detail of the diode connections within the hybrid junction.

The RF signal is fed to the diodes via a 50-Ω CPW, CPW-to-slotline transition, tapered slotline, and hybrid junction. The LO signal is applied to the diodes through a 50-Ω CPW, CPW end-coupled bandpass filter, and hybrid junction. The hybrid junction allows the RF and LO signals to arrive at the diodes 180° out-of-phase and in-phase, respectively. The IF signal is extracted via a CPW low-pass filter.

The CPW-to-slotline transition is designed to transfer a 50-Ω CPW to a 50-Ω slotline. The length of the radial slotline stub is approximately a quarter-wavelength at 11 GHz. Two such transitions, separated by a 0.375-in 50-Ω slotline, were fabricated on an RT/Duroid 6010 substrate having a relative dielectric constant of 10.2 and thickness of 0.050 in. The measured return and insertion losses are better than 11 and 1 dB from 6.4 to 10.5 GHz, respectively. Over the same frequency range, the amplitude and phase balances of the transitions are within 0.6 dB and 7°, respectively. Design and performance of this kind of transition can be found in [2]. The tapered slotline is used to provide a match from the 50-Ω slotline to the two diodes at the RF frequencies. The diodes are mounted across the slotline with their common junction connecting to the CPW. These diodes appear in series with respect to the RF port and in parallel to the LO and IF ports, thus rendering easy impedance matching to these ports. The hybrid junction, shown in Fig. 2, is the heart of the balanced mixer and is easily realized by two orthogonal transmission lines: the (balanced) slotline and the (unbalanced) CPW. The electric fields of the signals arriving from the slotline and CPW are indicated by the solid and dashed arrows, respectively. These special field behaviors allow the 180° out-of-phase and in-phase at the two gaps of the junction where the diodes are mounted to be inherently achieved and, thus, create a very wide-band hybrid. The bandpass filter is an end-coupled filter [3]. It is designed to pass the

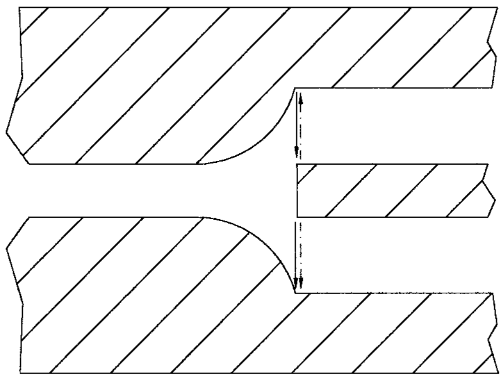

Fig. 2. Hybrid junction used in the mixer.

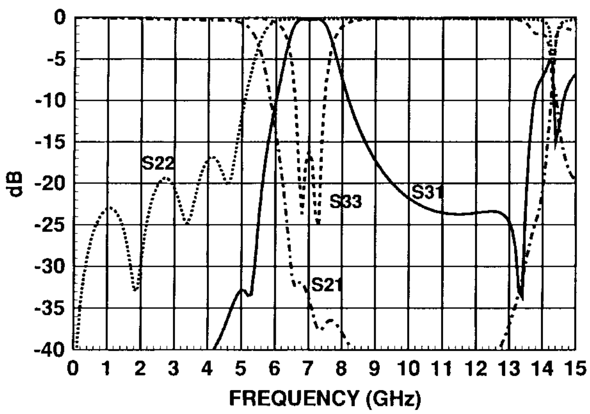

Fig. 3. Calculated frequency response of the combined bandpass/low-pass network.

LO signal from 6.7 to 7.3 GHz, while approximately providing an open circuit to the IF signal. It can, therefore, substantially reduce the loading effect of the LO network on the IF circuit and minimize the leakage of the IF signal through the LO port. The low-pass filter employs multiple sections of low/high characteristic-impedance CPW's. It is designed to pass the IF signal from dc up to 5 GHz and provide an approximate open circuit at both the RF and LO frequencies. The design of these bandpass and low-pass filters are well established, and it is well known that they perform close to the theoretical calculations. Therefore, experimental evaluations of these individual filters were not carried out.

The LO bandpass and IF low-pass filters were first designed individually and then connected together to model the interaction between them. As expected, this interaction degraded the circuit performance, which required further optimization using the commercially available LIBRA computer program.[1] Fig. 3 shows the calculated performance of the combined bandpass/low-pass network after optimization. The return loss of the IF port (S_{22}) is more than 22 dB from dc to 3.5 GHz and that of the LO port (S_{33}) is better than 21 dB from 6.7 to 7.3 GHz. S_{21} and S_{31} represent the insertion losses corresponding to S_{22} and S_{33}, respectively.

In this mixer, the RF signal propagates as an (odd) slotline mode, whereas the LO and IF signals operate in the (even) CPW mode, thereby achieving inherent RF-to-LO and RF-to-IF isolations. Various air-bridges are used along CPW's to ensure equal potentials of the ground planes to suppress propagation of the slotline mode. Although approximate design and analysis of this mixer can be performed using LIBRA's nonlinear capability, obtaining accurate results using this

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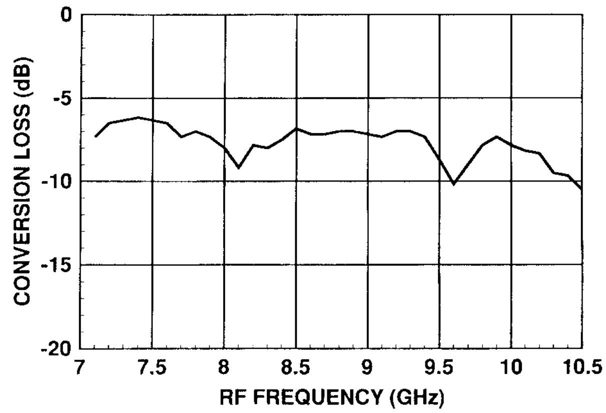

Fig. 4. Measured conversion loss versus RF frequency. $P_{\mathrm{RF}} = -10$ dBm and $P_{\mathrm{LO}} = 3.5$ dBm at 7 GHz.

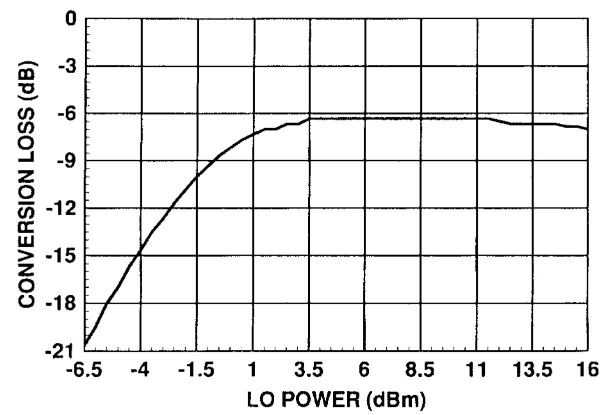

Fig. 5. Measured conversion loss versus LO power at 7 GHz. $P_{\mathrm{RF}} = -10$ dBm at 9 GHz.

software is nearly impossible. This is mainly due to the fact that this program does not have models for the employed CPW-slotline transition, hybrid junction, and tapered slotline. Therefore, we decided to empirically approach the problem based on a linear analysis, in which we designed individual elements independently (as described earlier) and then connected them together to form the final mixer. As will be seen, even though such an approximate design had been implemented, decent results for the first design were achieved.

III. Mixer Performance

The mixer was fabricated on an RT/Duroid 6010 substrate with a relative dielectric constant of 10.2 and thickness of 0.050 in. The diodes used are ALPHA DME 2333 silicon beam–lead Schottky barrier diodes having a junction capacitance of approximately 0.1 pF and a series resistance of 13 Ω.

Fig. 4 shows the measured conversion loss of the first-iteration design when the RF is swept from 7.1 to 10.5 GHz and the LO is fixed at 7 GHz. With the LO power of only 3.5 dBm, the conversion loss is from 6 to 10 dB. Although this result of the conversion loss is not spectacular at this frequency range, it demonstrates the workability of the proposed mixer configuration. With further optimizations, a better conversion loss over a wider bandwidth can be obtained. However, this is beyond the scope of this paper, as our purpose is to demonstrate the feasibility of this mixer topology. Fig. 5 shows a typical measured conversion loss versus the LO power. With the RF power level fixed at -10 dBm at 9 GHz and the LO at 7 GHz, the conversion loss reduces from 20 to 6 dB as the LO power increases from -6.5 to 3.5

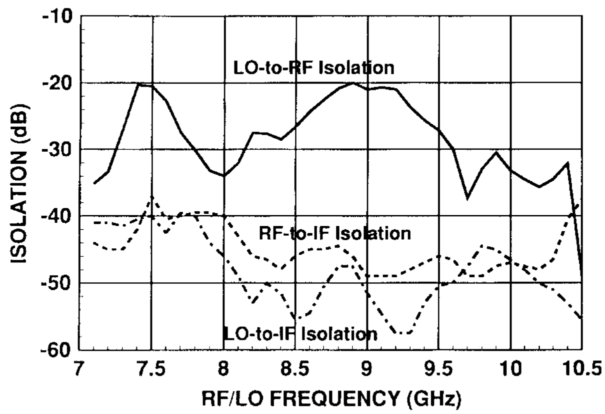

Fig. 6. Measured interport isolations.

dBm, and it does not vary when the LO power level increases from 3.5 to around 11 dBm. Fig. 6 shows the measured interport isolations of the mixer. The LO-to-RF isolation is higher than 20 dB, and the RF-to-IF and LO-to-IF isolations are better than 36 dB. Return losses at the three ports were also measured. When the LO power is 3.5 dBm, the LO port exhibited a return loss of better than 10 dB from 6 to 8 GHz. For the LO frequency of 7 GHz used in the foregoing data, a 20-dB return loss was obtained. The return losses at the RF port were from 11 to 27 dB over 7.1 to 10 GHz and 7 to 11 dB between 10 and 10.5 GHz. The measured IF port's return losses range from 11 and 17 dB over 0.1 to 3.5 GHz. These RF and IF return losses were measured when the mixer diodes were pumped by an LO power of 3.5 dBm at 7 GHz.

IV. Conclusion

A new broad-band uniplanar singly balanced diode mixer has been developed. A conversion loss from 6 to 10 dB (where the RF is swept from 7 to 10.5 GHz and the LO is fixed at 3. 5 dBm at 7 GHz) has been measured for the first-iteration mixer design. More than 20 and 36 dB have also been achieved for the LO-to-RF and LO(RF)-to-IF isolations, respectively. Good return losses at the RF, LO, and IF ports have also been measured. This mixer has the advantages of wide bandwidth, good interport isolations, and simple circuit design. The complete uniplanarity of the mixer is very suitable for low-cost MIC and MMIC manufacturing.

Acknowledgment

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A Two-Channel Optical Downconverter for Phase Detection

Paul D. Biernacki, Lee T. Nichols, D. G. Enders, Keith J. Williams, and Ronald D. Esman

***Abstract*— Experimental results for a two-channel optical downconverter link operating from 2 to 18 GHz are presented. Using low-noise preamplifiers results in a noise figure (NF) of 8.5–14 dB over the frequency range of 2–18 GHz. For the first time, relative phase measurements between optically downconverted signals have been performed. An in-phase/quadrature phase-measurement technique indicates a phase precision of $\pm 2^{\circ}$ with as little as -60 dBm radio frequency (RF) received power. Comparing the optical microwave downconverter to an electrical microwave downconverter in terms of phase detection reveals similar performance between the two systems.**

***Index Terms*—Downconversion, fiber-optic link, microwave phase detection, photonics, remoting.**

I. Introduction

Radio frequency (RF) receiving or transmitting systems with multigigahertz bandwidth operation can be more easily and reliably implemented using commercial off-the-shelf optoelectronic components. A downconverting optical system capable of detecting the relative phase of microwave signals offers the possibility of reduced weight, smaller size, and fewer components at the antenna location, while still providing essential microwave functionality. The attractiveness of fiber-optics technology primarily comes from its exceptional RF isolation, its ability to remote microwave signals great distances, and its immunity to electromagnetic interference (EMI). Additionally, use of a lightweight optical modulator as a microwave sensor makes it possible to remotely operate the downconverter since the local oscillator (LO) power can be carried through an optical fiber.

We demonstrate that by using cascaded modulators [1], optical amplification [with an erbium-doped fiber amplifier (EDFA)], balanced detection, and low-noise preamplifiers (DBS #DB96-0625) in our system configuration, a 22-dB noise figure (NF) improvement over our previous system [2]–[3] is achieved. Additionally, the two-channel configuration offers the ability to remotely determine the relative phase of microwave signals. To our knowledge, this is the first ever two-channel optically downconverting detection system. To characterize this system, we used an in-phase/quadrature phase (I/Q) measurement technique. Phase detection is a basic function required for sensitive direction-finding antenna systems utilizing phase interferometry [4]. Phase detection also enables the demodulation of complex microwave communication signals such as phase shift keying (PSK), quadrature PSK (QPSK), or many phase-level PSK (M-ary PSK). Therefore, I/Q measurements give us a good indication of how well these functions could be performed by photonic systems.

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P. D. Biernacki, L. T. Nichols, K. J. Williams, and R. D. Esman are with the Naval Research Laboratory, Code 5672, Washington, DC 20375 USA.

D. G. Enders is with the Naval Research Laboratory, Code 5726, Washington, DC 20375 USA.

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