A NEW PLANAR DOUBLE-DOUBLE BALANCED MMIC MIXER STRUCTURE

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ABSTRACT

Coplanar waveguides, slot lines and coplanar strips are combined to realize a MMIC double-double balanced mixer (DDBM) in which all circuitry is on the top side of the substrate and no via holes are required. The DDBM exhibits RF, LO, and IF bandwidths of 6-20 GHz, 8-18 GHz and 2-7 GHz respectively with conversion loss ranging between 6.2 and 9.8 dB, and RF to IF, LO to IF and LO to RF isolations all greater than 20 dB. The mixer was designed analytically using the harmonic balance method to assess key performance parameters. It is believed to be the first planar diode MMIC DDBM to be reported.

INTRODUCTION

Double-double balanced mixers (DDBM) are an important class of mixer because they facilitate overlapping RF and IF bandwidths while still providing RF to IF, LO to RF and LO to IF isolation. Most DDBM designs require separate RF, LO and IF baluns and eight diodes. Such a mixer is very difficult to realize in planar form. Techniques [1,2] such as orthogonal substrates, twisted Duroid structures and other means that are not easily amenable to MIC or MMIC fabrication have been used in previously reported DDBMs. The MMIC mixer described in this paper employs a novel mix of slot line, coplanar waveguide (CPW) and coplanar strips (CPS) and eight GaAs Schottky diodes and is fabricated on a 16 mil thick GaAs substrate without the use of via holes. The resulting mixer, although somewhat large at 180x240 mils is low in cost to fabricate. A MIC realization of the structures is also quite practical since the only components that must be attached to the substrate are the eight diodes.

The DDBM was carefully modeled and the harmonic balance method was used to assess the conversion loss, VSWR, isolation and spurious behavior of the mixer as a function of frequency and LO drive level. Circuit element values were manually adjusted to enhance performance but optimization was not feasible because of the length of time required by each analysis. The resulting DDBM operated over a RF bandwidth of 6 to 20 GHz, a LO bandwidth of 8 to 18 GHz and an IF bandwidth of 2 to 7 GHz with conversion loss ranging from 6.2 to 9.8 dB. RF to IF, LO to RF and LO to IF isolations were 25 dB, 23 dB and 20 dB respectively. The measured and simulated performance were in reasonable agreement.

MIXER CIRCUIT DESIGN AND MODELING

The DDBM is composed of an 180 hybrid, an IF balun and eight GaAs Schottky diodes. A photograph of the mixer is shown in Figure 1.

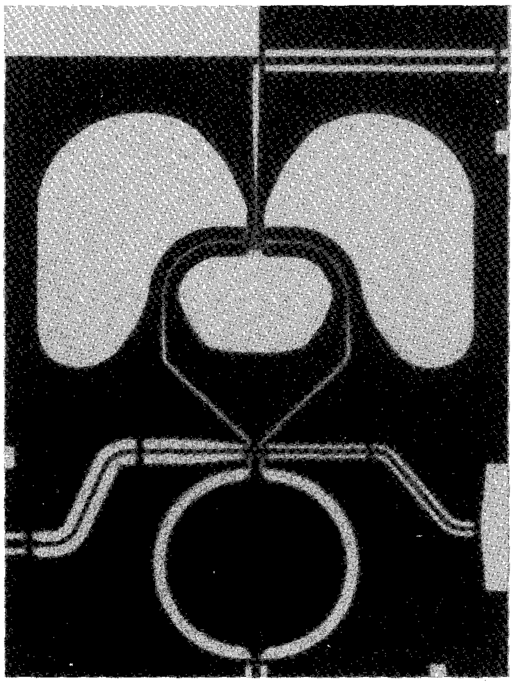

Figure 1a

Photograph of double-double balanced mixer chip showing RF, LO 180 hybrid, IF balun and dual diode ring. Chip size is 180x240x16 mils

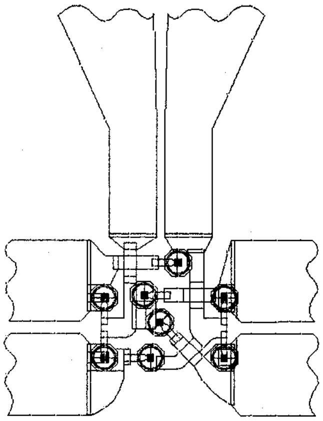

Figure 1b

Detail of dual diode ring showing connections to the RF-LO Hybrid and IF Balun.

The 180 hybrid employs CPW, CPS and slot lines and operates over a sum port bandwidth of 2 to 22 GHz and a difference port bandwidth of 5 to 20 GHz. The hybrid design builds upon previously reported Uniplanar technology [3, 4]. The signal driving the sum port is delivered via a 50 Ohm CPW line to a pair of three section transformers, each composed of two uncoupled slot line sections and a CPS section in cascade. Each transformer is designed to transform a 50 Ohm load at the CPS end to 100 Ohms at the slot line end where it is paralleled with another transformer properly terminating the sum input CPW. The difference port input CPW, the open circuited CPW stub, the circular slot line section and the output slot lines form a fourth order Marchand balun [5] covering the 5 to 20 GHz band. Inspection of the electric field vectors show that signals exciting the sum port appear at the output port in phase, while signals exciting the difference port arrive at the output ports out of phase. This yields an 180 hybrid with CPW inputs and CPS outputs. A layout of the hybrid is shown in Figure 2 with its equivalent circuit in Figure 3 and simulated performance in Figure 4. The simulation was accomplished by adding slot line and CPS models to the Libra circuit simulator.

The IF balun consists of a CPW to slot line transition followed by a slot line to CPS transition. [6] This structure is shown in Figure 5. All signals are delivered to the diodes on balanced CPS lines. The diodes have 3 micron diameter Schottky contacts air-bridged to the desired point of connection and exhibit a cutoff frequency in excess of 1000 GHz. The complete mixer shown schematically in Figure 6 was analyzed using the Libra harmonic balance simulator and element values were adjusted for best conversion loss. Agreement between measured and modeled conversion

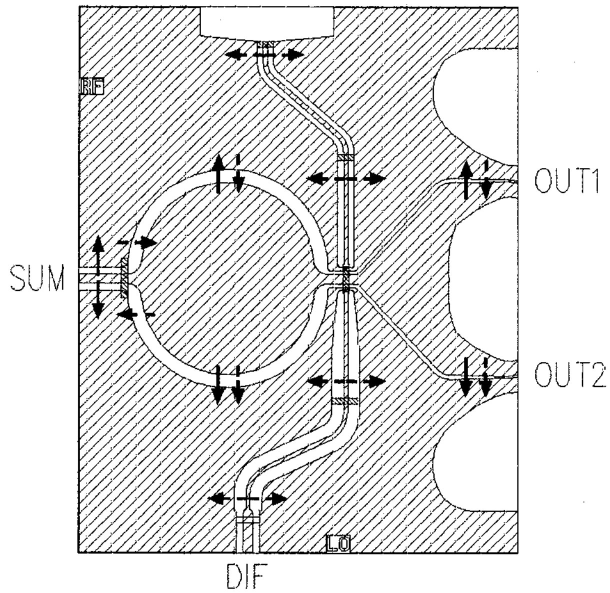

Figure 2

Layout of the 180 hybrid composed of CPW, CPS and slot lines. Signals incident on the sum port (solid arrows)are delivered in phase at the output ports while signals incident of the difference port (broken arrows) are delivered out of phase. The difference port is isolated from the sum port by the even mode short circuit provided by the air bridge near the sum port.

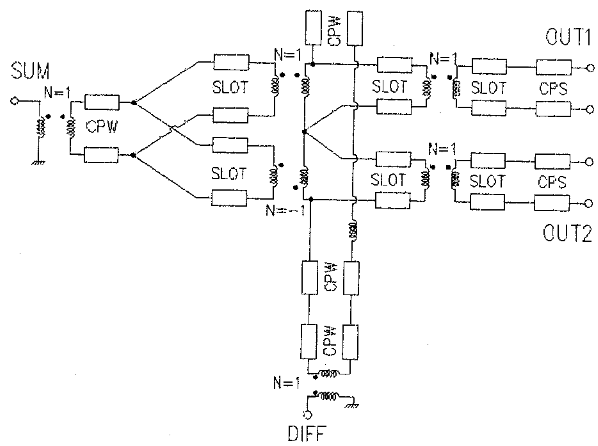

Figure 3

Equivalent circuit model of 180 hybrid is obtained by super-position of the individual odd and even mode equivalent circuits of the device. The Marchand Balun is composed of the DIF port CPW transformer section, the CPW open stub and the slot lines to the left and right of the junction.

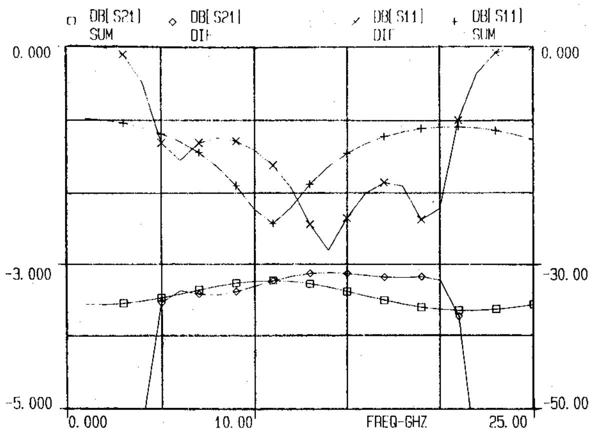

Figure 4

Computed performance of 180 hybrid. Circuit simulation included accurate CPW, CPS and slot line models but ignored junction discontinuation. Return loss was 12 dB minimum on all ports, coupling was 3.4±0.25 dB and phase difference was 180±22° across the 5-20 GHz band.

loss was within 1.5 dB at each frequency. This is reasonable considering the fact that transmission line discontinuity effects were ignored and that the analysis used a harmonic number of five, requiring the simulation to be accurate to at least 100 GHz.

FABRICATION AND MEASURED PERFORMANCE

The MMIC was fabricated on 16 mil thick GaAs substrates. A simple MBE material structure, consisting of 1200 Å of 2 x $10^{17}/cm^3$ N layer and 1800 Å of 2 x $10^{18}/cm^3$ N+ layer grown on a semi-insulated GaAs substrate, was used to fabricate the MMIC mixer. Standard front side MMIC processes were used. The Schottky dot was formed using Ti-Pt-Au first level metal. Ideality constants of 1.17 or less were routinely obtained. Since no via holes were needed in the design, no backside processing was required. This has reduced process complexity and significantly improved the yield. Figure 7 shows a typical Schottky diode fabricated using this process.

The chips were mounted in a CPW test fixture composed of tapered CPW lines on 20 mil alumina substrates with K series coaxial launchers. The mixer's RF bandwidth was 6 to 20 GHz, its LO bandwidth was 8 to 18 GHz and its IF bandwidth was 2 to 7 GHz. Since the RF, LO and IF bands overlap there is no possibility of filtering to eliminate undesired signals and the mixer's inherent isolation must be depended upon the reject these signals. The RF to IF, LO to RF an LO to IF isolation are 25 dB, 23 dB and 20 dB respectively. The mixer's conversion loss ranged from 6.2 to 9.8 dB. The RF input power for 1 dB compression was +8.5 dBm and the third order input intercept point was +20 dBm. Worst case VSWR was 3:1 at any port. These data are tabulated in Table 1.

CONCLUSION

A new planar double-double balanced mixer structure suitable for either MIC or MMIC fabrication has been described. The mixer uses only transmission lines and eight Schottky diodes and is easy to fabricate in both media since capacitors, resistors and vias are not required. The entire circuit is printed on one side of a single substrate without the need for tricky nonplanar assembly techniques. The performance of the new DDBM is excellent, making it a useful component for future wideband systems.

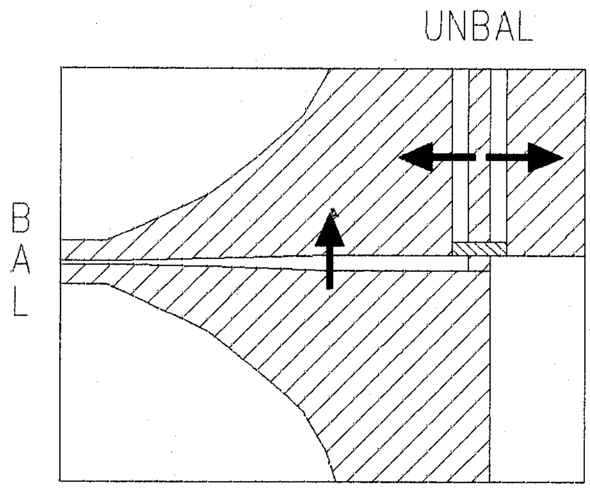

Figure 5

The IF balun structure is formed by transitions from CPW to slot line to CPS.

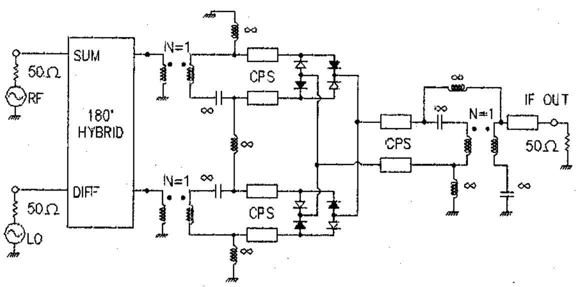

Figure 6

Equivalent circuit used for harmonic balance analysis showing diode connections and infinite value L's and C's added to set up proper d.c. initial conditions.

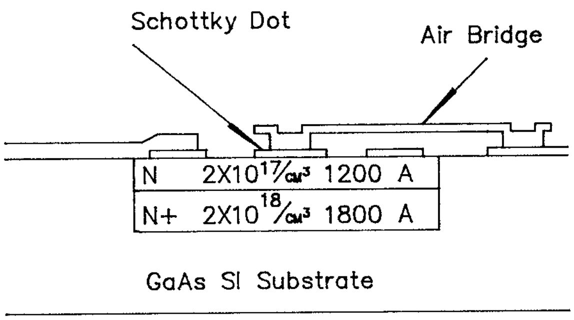

Figure 7

Cross section of Varian MMIC Mixer Diode

RF Bandwidth	6 - 20 GHz
LO Bandwidth	8 - 18 GHz
IF Bandwidth	2 - 7 GHz
RF Port VSWR	2.5:1
LO Port VSWR	3.0:1
IF Port VSWR	3.0:1
LO Power	+ 17 dBm
Conversion Loss	9.8 dB max, 7.5 dB typ
LO-RF Isolation	23 dB min.
LO-IF Isolation	20 dB min.
RF-IF Isolation	25 dB min.
RF Pin @ 1 dB Comp.	+ 8.5 dBm
RF Input 3IP	+20 dBm

Table 1. Summary of MMIC Mixer Performance

ACKNOWLEDGMENT

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