UNILATERAL MICROSTRIP BALANCED AND DOUBLY BALANCED MIXERS

Reinhard Knöchel, Bernd Mayer, and Uhland Goebel

Technische Universität Hamburg-Harburg
Arbeitsbereich Hochfrequenztechnik
Postfach 90 14 03, D-2100 Hamburg 90
West Germany

ABSTRACT

Possibilities for the uniplanar realisation of balanced and doubly-balanced microstrip mixers are discussed. Several novel mixer designs are presented, which can be used for miniaturization or for broadbanding the performance, using simple and noncritical branchline structures. The feasibility of the structures is verified experimentally. Relative bandwidths up to approximately 45% are reached easily.

INTRODUCTION

Numerous mixer circuits have been published in the past. Whereas balanced mixers can be constructed with 0°-90°- and 0°-180°-hybrids, doubly balanced mixers exclusively use 0°-180° hybrids or baluns /1/. Probably the best known balanced mixer realizations use the 0°-90°-branch-line or Lange-couplers or the 0°-180° rat-race coupler (Fig. 1). These circuits can be realized in strictly uniplanar microstrip i.e. a pattern has to be defined on one side of the substrate only. Nearly all the other realisations of balanced or doubly balanced microstrip mixers, which can be found in the open literature, utilize orthogonal lines or completely three-dimensional structures, and require photolithographical process steps and device mounting on both sides of the microstrip substrate. Examples are the well-known coplanar-slot junction and the balanced-line balun mixer (Fig. 2). Although many of these realizations are very elegant and extremely broadband, there is still a need for strictly uniplanar balanced- and doubly-balanced mixer solutions. This is because uniplanar circuits are much easier to fabricate, are more reliable, and are amenable for monolithic integration or realization on dielectric substrates with thick metal backings. With respect to such techniques, metallized via holes and air bridges can be tolerated (as it is needed for example for a Lange--coupler or a bias return).

The scope of this paper is to discuss the possibilities for uniplanar balanced- and doubly-balanced mixer realizations, and to introduce some novel designs.

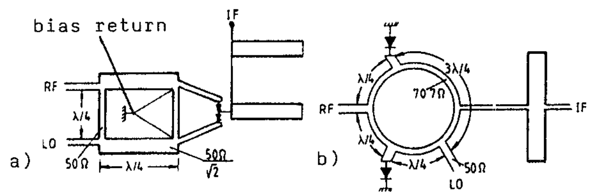

Fig. 1: Balanced mixers with
a) branchline hybrid (90°)
b) rat-race hybrid (0-180°)

BALANCED MIXERS

This paper will only discuss the 0°-180°-type of balanced mixers. When realized in microstrip, a beam-lead diode pair can be modelled as a three--port, as is shown in fig. 3. One signal, for example the LO, has to be applied out-of-phase to the diodes. The required odd-mode-network then has to be connected to ports (1) and (2). With respect to this signal, port (3) is a virtual short and hence can be connected to an arbitrary impedance. The RF-signal has to be applied in-phase. If the related even-mode network is connected also to ports (1)

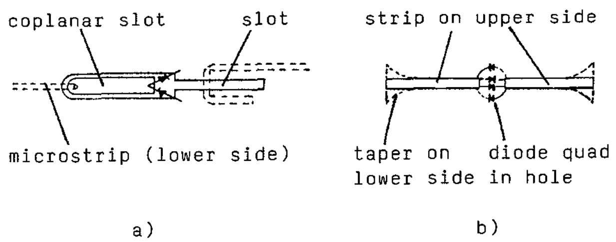

Fig. 2: Quasiplanar mixers
a) single-balanced coplanar-slot-junction
b) doubly-balanced tapered balanced line

and (2), this requires that port (3) be terminated in a short circuit. The even-mode network has to show high input-impedance at ports (1) and (2) with respect to the odd-mode network and vice versa. In uniplanar form, this kind of mixer can be obtained by using the circuit of fig. 1a with an additional 90° linelength in one connecting arm of the diodes, or with the rat-race hybrid of fig. 1b. The requirement of high network input impedance at the ports (1) and (2) significantly restricts the usable bandwidth. Both even- and odd-mode networks have to be designed with a prescribed input impedance.

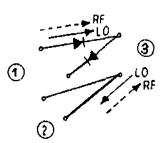

Fig. 3: Diode-pair for a single balanced mixer modeled as a three-port.
Arrows indicate the LO and RF excitation.

The design becomes much more flexible if port (3) is used as the even-mode entrance. Since a virtual short exists at this port for the odd-mode signal, the network can be designed freely with respect to input impedance, fulfilling other design objectives. The odd-mode-network, connected to ports (1) and (2) now has to present a short-circuit under even-mode excitation. This has to be achieved by means, which do not deteriorate the out-of-phase signal. Such a requirement, however, can be fulfilled rather easily, by constructing the odd-mode network, as seen from ports (1) and (2) partly symmetrical (at least one branch). In the center-plane of the symmetrical branch, a virtual open for even- and a virtual short for odd-mode excitation exists. This can be transformed to the ports (1) and (2) in order to present a short for the even mode but an open for the odd-mode.

Following these guidelines, several novel mixer designs can be found. Fig. 4a presents the most simple but narrowband solution. The odd-mode network consists of a (folded) half wavelength line. At the design frequency, both diodes are fed in antiphase. This line, however, when driven in the even mode, transforms the open circuit present at the 180° bend via its length into a short circuit at the diode ports. The circuit of fig. 4a can be broadbanded by adding another $\lambda/2$-wavelength long line $\lambda/4$ apart from the first. Then the second line can be used to compensate the first line with respect to even-mode short circuit and odd-mode antiphase behaviour. It is interesting to note, that, if the RF-network is replaced by a short circuit and the folded $\lambda/2$-wavelength branch is fed at its center-point, a rat-race-like mixer would result.

The broadbanding procedure can be continued by adding more $\lambda/2$-wavelength long lines with $\lambda/4$-interconnecting lines, as is sketched in fig. 4c, for example. A broadband transformer can be added at the RF-port, too.

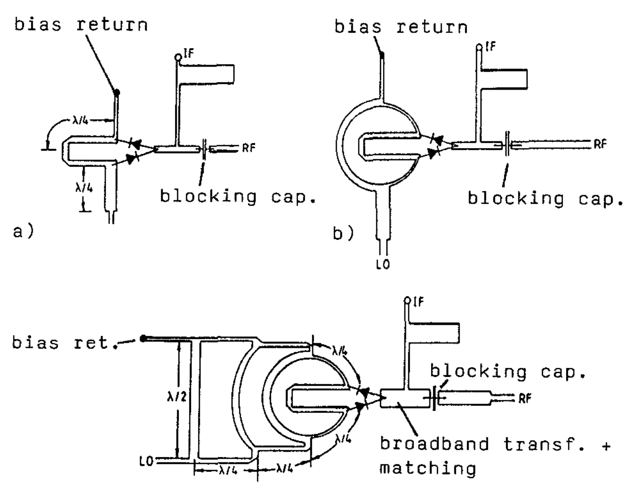

Fig. 4: Various balanced mixers
a) narrow-band miniature mixer
b) mixer with additional compensating path
c) broadband-mixer

It shall be mentioned, that the circuit of fig. 4a can be combined with broad-band-baluns, too, which inherently show a rapidly varying input impedance, when seen from the 180°-port. In these cases, the folded λ/2-wavelength branch guarantees the virtual short for in-phase excitation at ports (1) and (2). Two possible solutions are depicted in fig. 5, using a 180° Schiffman phase-shifter /2/, fig. 5a, or a balun using Lange-couplers /3/, fig. 5b.

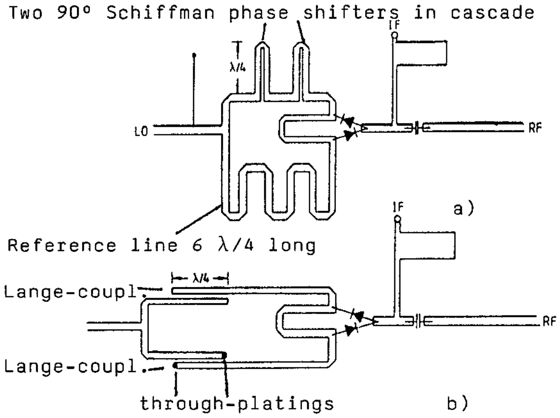

Fig. 5: Other possibilities of uniplanar balanced mixers a) using cascaded 90° Schiffman phase-shifters b) balun with Lange-couplers

DOUBLY BALANCED MIXERS

The various diode-quads, which can be used in doubly balanced mixers, are shown in fig. 6. The ring-quad has to be driven by odd-mode-networks from the ports (1) and (2), or (3) and (4), respectively. When driven from one of these pairs of ports, the corresponding diagonal ports are virtual grounds and can be connected to odd-mode-networks of arbitrary input impedances.

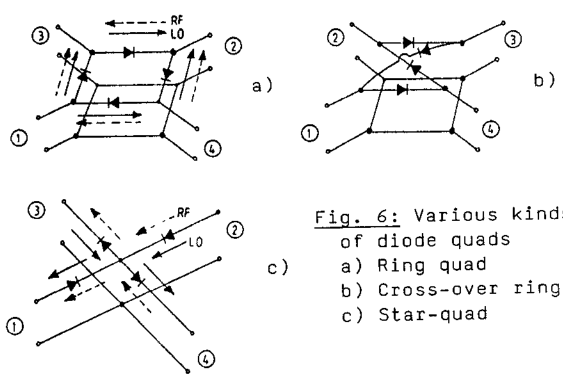

Fig. 6: Various kinds of diode quads
a) Ring quad
b) Cross-over ring
c) Star-quad

All the odd-mode networks from fig. 4 and 5 could be chosen, depending on the bandwidth required. An example is given in fig. 7 using the odd-mode network of fig. 4b. The inner λ/2 wavelength long lines of the odd-mode-networks have been folded outside, and the IF is picked up at the center points. Four air-bridges are needed due to topological reasons. The two IF components are also in anti-phase and can be combined via a toroidal balun transformer which renders possible IF-frequencies typically between 50 MHz and 3 GHz. Only one air bridge is needed when the outside-folded lines are ommitted, which is possible, since the input impedance at the diagonals can be chosen freely.

No airbridges are required when choosing the cross-over quad of fig. 6b. An example of such a mixer is given in fig. 8. Other odd-mode networks including the baluns of fig. 5 could be chosen also.

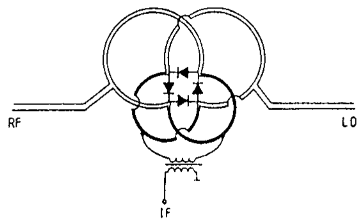

Fig. 7: Doubly balanced mixer with broadband balanced IF-output

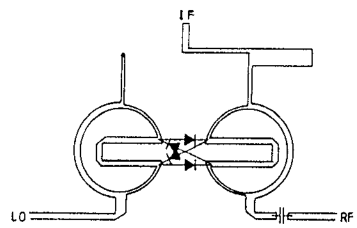

Fig. 8: Example of a doubly balanced mixer using a cross-over quad

Finally, the star-mixer shall be discussed. The star-quad (fig. 6c) has to be driven simultaneously at ports (1) plus (4) and (2) plus (3) by an odd--mode signal /1/. The second driving network is connected orthogonal to the first at the same ports (driving (1) plus (3) and (2) plus (4)) and has to present high impedance to the ports. A possible solution is given in fig. 9, using a cross of λ/4-wavelength lines, as is proposed in /1/.

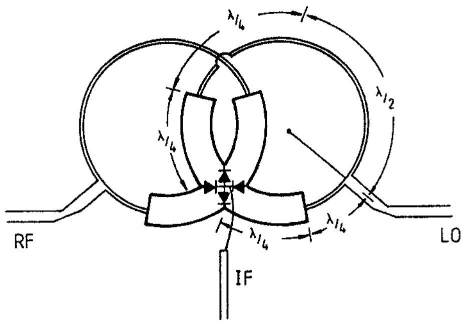

Fig.9: Star mixer

EXPERIMENTAL WORK

Several mixer circuits were built up. The circuit patterns were first estimated, using approximate design rules, and then optimized with SUPER-COMPACT /4/ for minimum return loss and maximum isolation over the frequency range from 8 - 12 GHz (X-Band).

The presented mixer circuits use very simple and noncritical circuit patterns. Thin substrate material with low ε_r is suited best for the realisation, if beam-lead diodes are connected directly to the 0°/180°-output ports without intermediate transmission-lines. The first λ/2-line has to be folded in order to fit to the diodes. Further compensating lines are routed around the folded line.

Doubly balanced mixers and single balanced mixers worked equally well with low conversion loss and noise figure across the whole X-Band. Examples are given for the mixers of fig. 4a (first order mixer) and 4b (second order mixer) in fig. 10a and b, respectively, using low cost silicon diode pairs (HP-HSCH-5511). The difference in mixer bandwidth becomes obvious in fig. 11, where the LO to RF-isolation is plotted for a first, second and third order balanced mixer. As can be seen, the isolation is broad-banded and increases with increasing order. This indicates, that the 0°/180° phase relation and equal amplitude balance is greatly improved by using additional coupled λ/2 lines. Using the presented structures, mixers can be designed with a prescribed isolation over a given bandwidth.

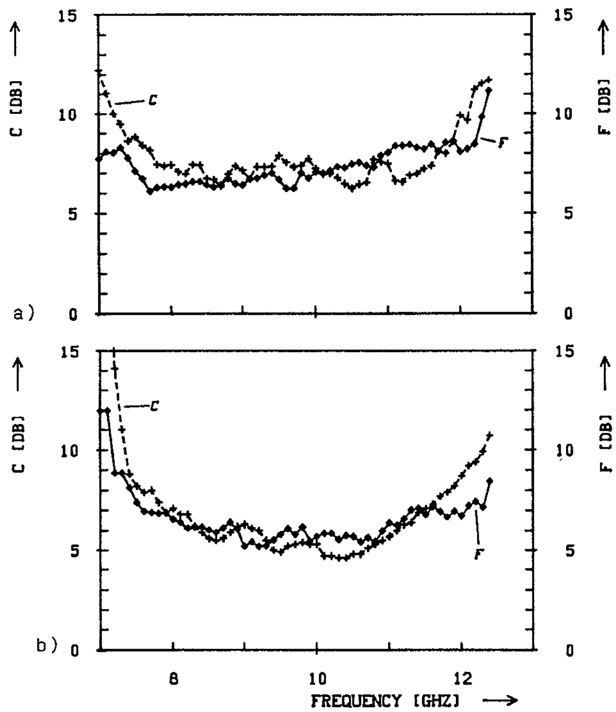

Fig. 10: Conversion loss and noise figure
a) first b) second order mixer

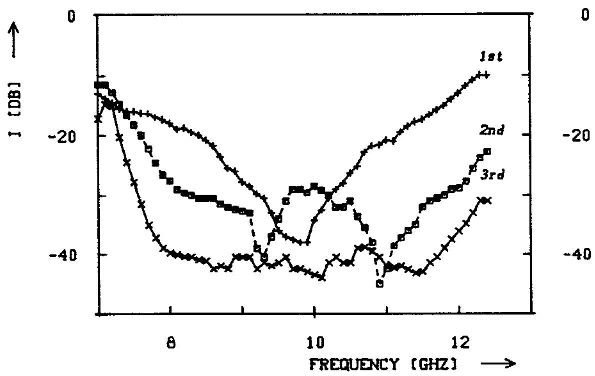

Fig.11: Isolation properties for mixers of various orders

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