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# AN INTEGRATED KU-BAND QUASI-PLANAR CIRCUIT MIXER

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## ABSTRACT

This paper describes a Ku-band integrated circuit balanced mixer using commercially available beam-lead diodes. Etched from a 17.5$\mu$m-copper cladded RT-Duroid 5880 substrate of thickness 254$\mu$m, the planar circuit board is sandwiched between the two parts of a waveguide split-block housing. Since the manufacturing accuracy mainly depends on the low etching tolerances, the design is especially suitable for millimeter-wave applications. 8 dB conversion loss, 5.6 dB DSB noise figure and isolation values of 35 dB are obtained for the Ku-band prototype operating in the self-biasing mode.

## INTRODUCTION

New developments of integrated microwave and millimeter-wave mixer circuits [1] have found many applications in modern communication systems. Particularly quasi-planar configurations, where a planar circuit is embedded in a waveguide split-block housing, are attractive components in terms of fabrication simplicity and cost reduction. An additional advantage is the integration possibility of complete systems such as receiver or radar modules [2].

This paper describes a quasi-planar circuit mixer as part of a Ku-band E-plane integrated front-end system. Based on earlier works of Menzel and Callsen [3, 4], the new features of the realized prototype include an optimized lowpass IF filter in shielded E-plane microstrip technology and an improved RF mode reflection circuit.

Since it has been shown that the finite metallization thickness and, particularly, the groove depth to fix the substrate have a major influence on the wave impedances and propagation constants, these parameters are calculated by the rigorous hybrid mode analysis presented in [5, 6].

## MIXER SETUP AND DESIGN

The planar mixer circuit, which is embedded in a waveguide split-block housing, is etched from a 17.5$\mu$m-copper cladded RT-Duroid 5880 substrate of thickness 254$\mu$m. The different quasi-planar cross-sections involved and the basic layout are shown in Fig. 1. The RF port comprises unilateral finline, coplanar and shielded microstrip circuitry, the LO port involves asymmetrical bilateral finlines; a shielded microstrip lowpass and a short triplate section connect the IF to the output port.

The RF signal is fed to the mixer via the unilateral finline taper driving the diodes in even mode operation. To focus the maximum signal level in the diode plane and to prevent the signal from reaching the IF port but, at the same time, allow for propagation of the microstrip-coplanar mode, the finline mode may be quasi short-circuited a quarter-wavelength behind the diodes. This is accomplished by reducing the waveguide cross-section and simultaneously increasing the slotwidth to achieve a below cutoff operation for this mode.

The local oscillator is fed to the diodes via an asymmetrical bilateral finline taper. The 90 degree transition to the microstrip followed by the coplanar line is basicly a shielded and slightly modified version of the standard microstrip-slotline transition which is often used in semiconductor-equipped double-sided planar circuits, e.g. [10]. Since only the strip mode (equivalent to the coplanar mode) can propagate in the reduced cross-section towards the RF port, the diodes are driven in odd mode operation, which results in ideally decoupled RF and LO signals. Practically, the isolation depends on the choice of equal diodes and on the symmetry of the layout. A sliding short is placed opposite to the LO port to account for optimum coupling from the slot to the microstrip mode.

The most critical part of this design, is the shielded microstrip IF filter. First, it should provide sufficient LO-IF isolation; second, the 50 Ohm output port has to be matched to the 120 Ohm diode and finline circuitry. The lowpass is realized by cascading high-low impedance sections [7]. However, there are certain limits for the impedance range. The maximum impedance is given by the minimum feasible strip width due to the etching facilities available. The minimum impedance (broadest section) is determined by the requirement that the first higher-order mode cutoff frequency must be well above the LO for a good LO-IF isolation.

Therefore, the cutoff-frequencies, propagation constants and characteristic impedances of the different cross-sections involved are calculated by applying a rigorous hybrid mode analysis [5, 6]. Mode-matching techniques in the cross-sectional plane and the incorporation of related boundary (resonance) conditions lead to a homogeneous matrix equation system which has non-trivial solutions only for a vanishing determinant. Either the cutoff frequency can be determined by setting the propagation constant to zero or, for a given frequency $f$, the calculation of the propagation constant $k_z$ leads to the actual guide wavelength $\lambda_g$ and the effective relative dielectric constant $\epsilon_{reff}$

$$\lambda_g = \frac{2\pi}{k_z} = \frac{c}{f\sqrt{\epsilon_{reff}}} , \tag{1}$$

where $c$ is the velocity of light in free space. The characteristic impedance of a finline is then defined by

$$Z_0 = \frac{V^2}{2P} , \tag{2}$$

where $V$ is the slot voltage and $P$ is the power carried by the fundamental mode through the finline's cross-section area $F_c$.

$$P = \frac{1}{2}\text{Re} \left\{ \int_{F_c} (\vec{E} \times \vec{H}^*) \vec{e}_z dF \right. \tag{3}$$

As has been demonstrated in [5, 6], this method is able to include the finite metallization thickness as well as the mounting grooves to fix the planar structure between the two housing parts. The lowpass filter itself is designed by using transmission line theory and the optimization algorithm described in [8]. Finally, microstrip discontinuity compensation is applied according to expressions given in [9].

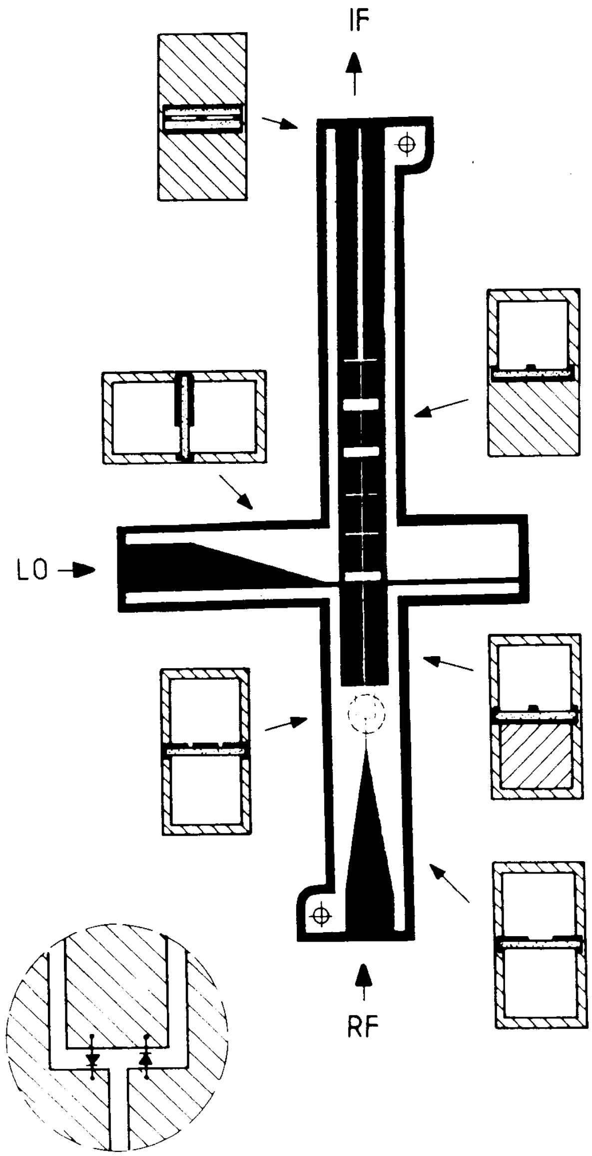


Figure 1.

Planar circuit balanced mixer layout and cross-sections obtained together with the waveguide split-block housing.

## RESULTS

Beam-lead Schottky diodes HSCH-5314 from Hewlett Packard were used for the mixer prototype operating in the self-biasing mode. Since no bonding facilities were available, the diodes have been mounted by soldering. Fig. 2 shows the output spectrum at the IF port. The local oscillator is set to 9 dBm at 13.725 GHz, the RF signal generator at 0 dBm at 15 GHz. As follows from Fig. 2 the conversion loss is about 8 dB at this frequency. Multiples of the intermediate frequency are suppressed by more than 30 dB. Remarkable is the -47 dBm LO level leading to an LO-IF isolation of more than 50 dB. Moreover, the measured LO-RF isolation of 35 dB demonstrates the good decoupling performance of the proposed design. It is assumed that the latter value can be shifted beyond 40 dB when using high-precision bonding techniques for mounting the diodes instead of soldering.

Figs. 3 show the measured conversion loss and the double sideband noise figure versus the intermediate frequency range. The average values are 8 dB and 5.6 dB, respectively. Nonlinear shaped finline taper sections are expected to improve the conversion loss by reducing the input reflection at the RF and LO ports. Furthermore, it is recommended that the LO power be increased to 12-15 dBm. A photograph of the planar circuit board together with the opened waveguide housing is shown in Fig. 4.

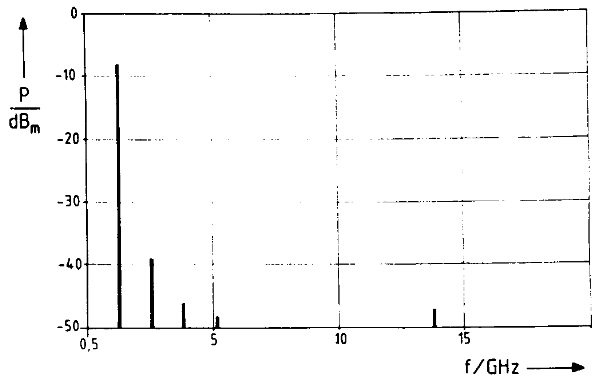


Figure 2.
Power levels at the IF output port (RF = 15 GHz, 0 dBm).

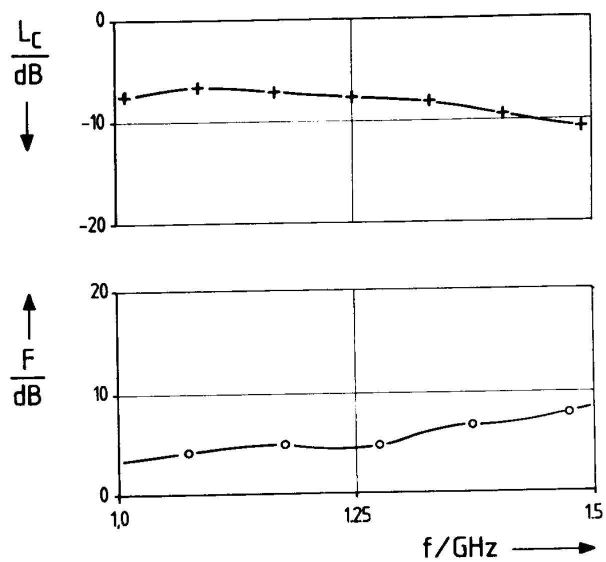


Figure 3.
Conversion loss (+) and DSB noise figure (0) versus intermediate frequency.

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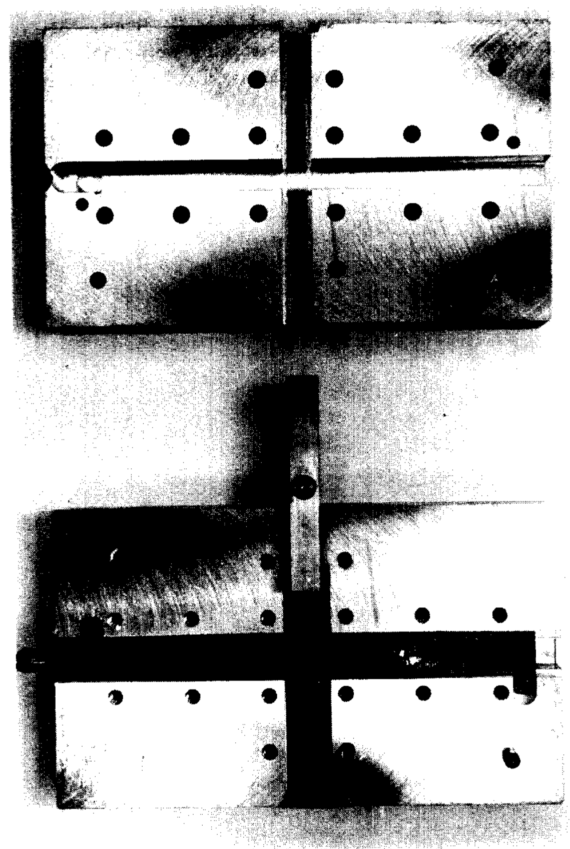

Figure 4. Photograph of the mixer prototype.

## CONCLUSIONS

An integrated Ku-band balanced mixer has been presented utilizing planar circuitry embedded in a waveguide split-block housing. Operating in a self-biasing mode, 8 dB conversion loss and a DSB noise figure of 5.6 dB have been measured. The good isolation values achieved between the three ports are due to the computer-optimized IF lowpass filter and a rigorous field theory calculation of the related finline and coplanar circuits.

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