# A MONOLITHIC 94 GHZ BALANCED MIXER

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## Abstract

On the basis of a recently developed GaAs technology, which allows the realisation of millimeter wave Schottky mixer diodes and MESFETs on the same monolithic chip, different 94 GHz monolithic mixers have been fabricated. The Schottky diodes show cutoff frequencies of up to 2.3 THz, whereas MESFETs with typical Fmax (MAG=1) of about 90 GHz have been measured. The mixer chips show conversion losses of less than 8 dB combined with noise figures below 6 dB (DSB).

## Introduction

Monolithic integration will be essential for future millimeter wave systems, which demand excellent quality in mass production combined with small size, low weight at affordable costs. Under these aspects the use of a technology is of great importance, which allows the integration of as many key components as possible on the same chip. In a first step a technology has recently developed, which demonstrated the successful integration of Schottky devices as mixer diodes, varactor diodes and MESFETs on the same wafer /1/. This allows the integration of MESFET oscillators, varactor multipliers, diode mixers and IF low noise amplifiers.

## Technology

The technology used for the fabrication of these 94 GHz mixers has been published elsewhere /2,3/ and has successfully been used for the realisation of 60 GHz mixers, IF amplifiers and receiver chips. The 10 mask fabrication process developed at Telefunken electronic is a combination of ion implantation to produce deep buried n+ layers with high conductivity and metal organic chemical vapor deposition (MOCVD) for epitaxial growth. The direct writing of fine structures like diode fingers and MESFET gates by electron beam lithograhpy allows structure sizes down to 0.3 um. Cutoff frequencies of about 2.3 THz for the Schottky diodes and typical Fmax values of about 90 GHz for MESFETs have been realized.

## Mixer design

The schematic cross section of a planar mixer diode is shown in fig. 1. Due to this structure a precise model of the diode has been developed. Each element of the equivalent circuit (fig. 2) for the diode has been described by an analytical equation taking into account parameters of the technology. The voltage dependent junction capacitance Cj and conductance Gj of the Schottky contact are

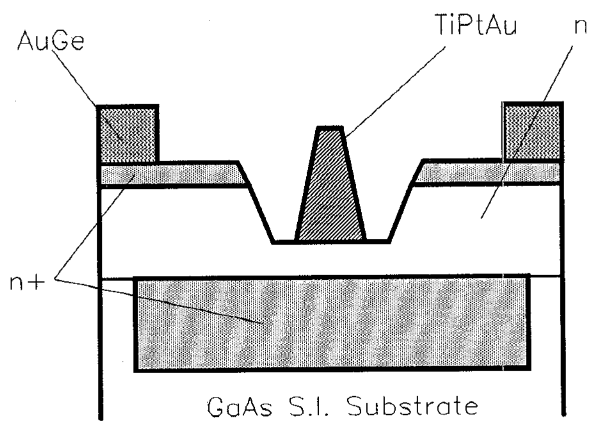


Fig. 1: A schematic cross section of a planar Schottky mixer diode



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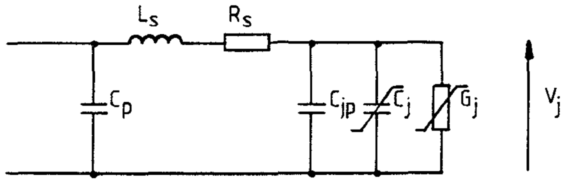


$$C_j = \frac{C_{jo}}{\left(1 - \frac{V_j}{V_{bi}}\right)^{\gamma}}$$

$$G_j = \frac{qI_o}{nkT} \exp\left(\frac{q\,V_j}{nkT}\right)$$

Fig. 2: Equivalent circuit of a Schottky diode

described by the classical relations given in the figure. The internal parasitic junction capacitance Cjp is due to the fringing effects. For a finger length of 0.3 um the value of this capacitance is of the same order as the parallel plate capacitance Cjo. The parasitic resistance Rs is composed of the ohmic contact resistance, the resistance between Schottky and ohmic contact, the resistance under the junction and the resistance of the finger metalization. The calculations are based on the transmission line method. For our devices we assume that the parasitic inductance Ls is negligible. The external parasitic capacitance Cp represents the coupling capacitance between ohmic and Schottky contact metalizations and is described by elliptic integrals of the first kind /4/. A computer program has been written, which describes the entire mixer configuration shown in fig. 3. The microstrip and its discontinuities are calculated using the magnetic wall model /5/. Due to the substrate thickness of 100 um an RF impedance level of 70 Ohms has been chosen. This leads to smaller stripwidths and reduced coupling effects between adjacent microstrip lines. Nevertheless the design of the branch line coupler takes into account the coupling effects between the lines of the ring and is a straight forward process. The bandwidth of this coupler was sufficient, because of an IF frequency range from 0.5 to 2.5 GHz was aimed at. One linelength between coupler and mixer diodes is a quarter of a wavelength longer than the other path to get the 180 degree balanced mixer configuration. Mixers with and without DC stops have been made. The DC stops in form of side coupled microstrip lines have been provided to allow biasing the mixer diodes, which reduces LO power consumption. RF ground and IF filter have been realized by using radial stubs. Software has been written on the basis of /6/ to design these stubs. Good agreement between calculation and measurement at 94 GHz has been achieved. To analyse the mixer behaviour with respect to conversion loss and noise figure the harmonic balance method has been used /7/. To achieve good mixer performance the impedances seen by the mixer diodes have been optimized for minimum noise figure and minimum LO power consumption taking into account the signal, image and intermediate frequencies.

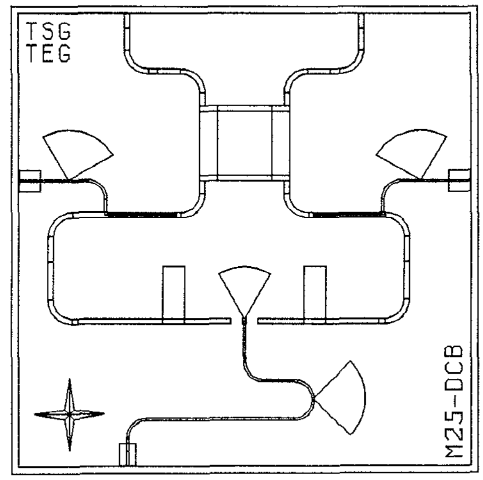


Fig. 3: Layout of a 94 GHz balanced mixer

## Mixer results

Several different mixers with and without DC stops have been fabricated. The measurements of the diodes in the mixers showed typical values of Rs=13 Ohms, N=1.2 and Cj=6fF which results into calculated cutoff frequencies of Ft=2 THz. Fig. 4 shows the conversion loss of a mixer chip including two DC stops versus LO power. A conversion loss of 8.5 dB associated with 5.5 dB noise figure (DSB) has been achieved using an LO power of 8 dBm. This LO power consumption can be reduced by biasing the

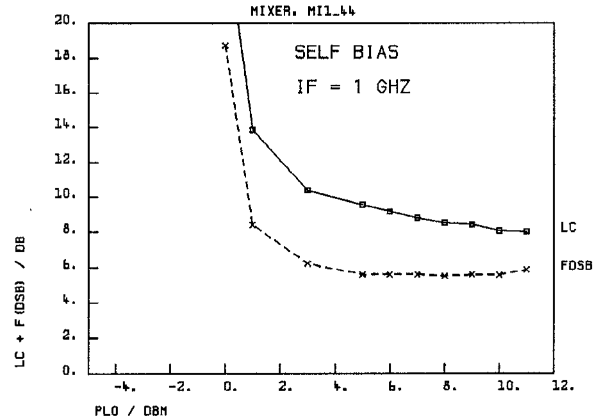


Fig. 4: Conversion loss and noise figure versus LO power of a mixer with DC-stop

mixer diodes, but compared to mixers without DC stops, and therefore only operating under self bias conditions, the effect was negligible. Despite self bias operation good results at low LO power rates down to 0 dB could be achieved with mixers without DC-stops as shown in fig. 5. The measurement values of a mixer without DC stops is shown in fig. 5. Here a

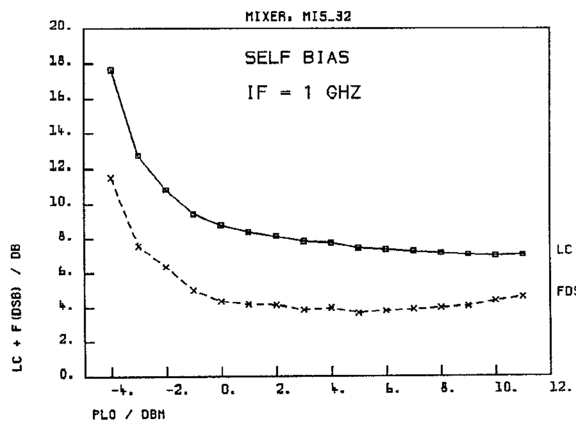


Fig. 5: Conversion loss and noise figure versus LO power of a mixer without DC-stop

conversion loss of 7.5 dB together with 4.0 dB noise figure (DSB) at only 5 dBm LO power has been measured. These results are better, because the sidecoupled DC stops have losses of about 0.8 dB and cause a mismatch between the hybrid coupler and the diodes. For the exact design of these DC stops the difference between odd and even impedance of the coupled microstrip lines should be 2 times the impedance level of the circuits, which is 70 Ohms. This is not quite possible and leads to a compromise as good as possible. Fig. 6 shows the measurement of conversion loss and noise figure versus IF frequency. A LO to RF port isolation of better than 12 dB have been measured.

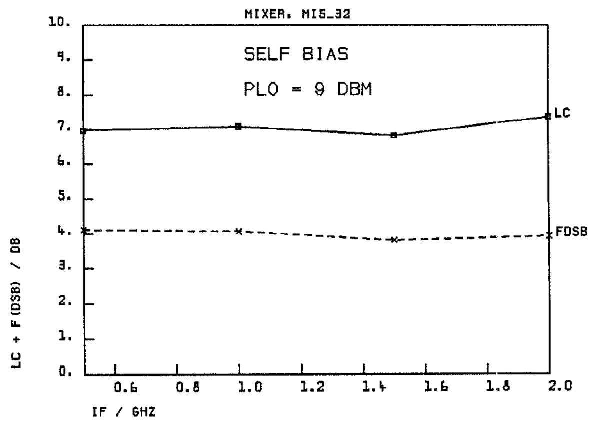


Fig. 6: Conversion loss and noise figure versus IF frequency

Conclusion

GaAs monolithic 94 GHz mixer chips have been fabricated. As best values a conversion loss of 7.5 dB with an associated noise figure of 4.0 dB (DSB) in self bias operation has been measured. The associated LO power consumption was 5 dBm. The used technology allows the integration and mass production of several key components on one chip, which are necesssary for millimeter wave receiver frontends.

Acknowledgements

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References

/1/ A.Colquhoun et al.: A fully integrated 60 GHz receiver, GaAs-IC-Symp. Digest, 1989, pp. 185-188

/2/ B.Adelseck et al.: A monolithic 60 GHz diode mixer in FET compatible technology, MMIC-S-Digest, 1989, pp. 91-94

/3/ B.Adelseck et al.: A monolithic 60 GHz diode mixer and IF amplifier in compatible technology, IEEE-Trans. on MTT, vol. 37, Dec 89, pp 2142-2147

/4/ R.A.Pucel et al.: Signal and noise properties of Gallium Arsenide Microwave Field Effect Transistors, Advances in Electronics and Electron Physics, Vol. 38, pp. 195-265 (Academic Press, NY, 1975)

/5/ W.Menzel, I.Wolff: A method for calculating the frequency dependent properties of microstrip discontinuities, IEEE-Trans. on MTT, vol. 25, Feb 77, pp 107-112

/6/ F.Giannini, R.Sorrentino, J.Urba: Planar circuit analysis of microstrip radial stub, IEEE-Trans. on MTT, vol. 32, Dec 84, pp. 1652-1655

/7/ D.N.Held, A.R.Kerr: Conversion loss and noise of microwave and millimeter wave mixers, IEEE-Trans. on MTT, vol. 26, Feb. 78, pp. 49-61