UNCLASSIFIED

Defense Technical Information Center Compilation Part Notice

ADP011773

TITLE: A 150 GHz Fully-Integrated MMIC Schottky-Mixer Array

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: International Conference on Terahertz Electronics [8th], Held in Darmstadt, Germany on 28-29 September 2000

To order the complete compilation report, use: ADA398789

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP011730 thru ADP011799

UNCLASSIFIED

A 150 GHz Fully-Integrated MMIC Schottky-Mixer Array

M. Rodríguez-Gironés, J.P. Pascual, S. Bäumel, C.I. Lin, H.L. Hartnagel

Abstract[1] - The development of detector arrays for two dimensional imaging of electron cyclotron emission[1] is essential for the investigation of heat transport and turbulent confinement in fusion plasmas. A new approach to imaging techniques is presented in which the quasi-optical coupling of pumping power is substituted by a direct on-chip distribution scheme using a fully MMIC multi-channel mixer circuit. The system makes use of a subharmonic mixer array designed in multisubstrate technology to perform 6 to 8 dB conversion loss. Aperture coupled patch antennas are used for the reception of plasma signal, whereas pumping power is fed to the mixer through a waveguide-microstrip transition.

I. INTRODUCTION.

The achievement of spatially resolved measurements of electron-temperature fluctuations within the core of fusion plasmas has become a fundamental issue in plasma diagnostics [2]. The investigation of heat transport as well as of the turbulent confinement requires two-dimensional imaging of Electron Cyclotron Emission (2D-ECEI) radiated at the plasma core. Among the methods to perform Electron Cyclotron Emission (ECE) radiometry, heterodyne mixing plays an important role [1]. The development of detector arrays for 2D-ECEI [3] represents today therefore one of the main concerns of plasma diagnostics.

ECEI systems realised to date (e.g. [4]) rely on quasi-optical coupling of the pumping power, using the same antenna as for signal reception. Simple approximations presented below show that loss of local oscillator (LO) power can be improved by a factor of about 10 dB if the coupling is performed directly on-chip.

The circuit is realised on a multi-substrate technology and includes aperture-coupled patch antennas for the reception of the plasma signal. Cross-talking between channels may be reduced by physical substrate separation to prevent propagation of substrate modes. Also patch antennas can be isolated to increase channel isolation.

On-chip coupling of LO power requires the use of subharmonic pumping in order to minimise frequency-dependent attenuation in the microstrip circuit. Therefore, anti-parallel diode pairs are selected as mixer elements, which improve subharmonic performance [5]. The technology necessary for the fabrication of such anti-parallel diode pairs is available [6] and can be adapted to the fabrication of large-area integrated circuits.

The MMIC circuit is made of four parallel sub-harmonic Schottky-diode mixers realised on microstrip line on a 70-μm thick GaAs substrate. The circuit layout is shown in figure 1. Each channel receives RF signal (plasma radiation) in the band 144 - 153 GHz through a patch antenna coupled to the microstrip circuit. The specified circuit bandwidth should be 9 GHz also at the IF (9 GHz to 18 GHz). Local-oscillator power (at 67.5 GHz) is coupled to a 50-Ω microstrip line on the chip.The total size of the chip is about 10 x 6 mm^2.

Simulated performance of the mixer systems show a minimum value of conversion loss between 6 and 8 dB for input LO powers ranging from 5 to 10 dBm per diode pair. The ripple throughout the IF band (9 to 18 GHz) is less than 4 dB.

II. SYSTEM CONCEPT

For each mixing channel, the patch antenna receives plasma radiation and delivers it through a slot in its ground plane to the microstrip circuit. In this way different substrates can be used for the patch antenna (fused quartz, ε_r = 3.4, with good radiation properties) and for the microstrip circuit (GaAs, ε_r = 12.8, with low radiation). Furthermore, the ground plane contributes to shield the mixer circuit, improving the circuit's isolation characteristics.

The multi-channel mixer system is mounted on a mixer block as shown in figure 1. The waveguide output of the LO source is coupled to the microstrip circuit and divided into four mixer channels. The intermediate frequency (IF) output is then coupled to coaxial cables before delivery to the IF section of the ECEI System.

An anti-parallel structure has been chosen for the diode configuration. This topology has well-known advantages ([7], [8]), in particular fundamental-mixing suppression and double LO mixing enhancement. It is still being employed for

[1] M. Rodriguez-Gironés, C.-I Lin, and H. L. Hartnagel are with the Institut für Hochfrequenztechnik, Techinshe Universität Darmstadt, Merckstr. 25, 64283 Darmstadt, Germany
J.P. Pascual is with the Universidad de Cantabria, Avda. de los Castros, s/n, Santander, Spain
S. Bäumel is with the MaxPlanck Institute for Plasma Physics, Boltzmannstrasse 2, 85748 Garching bei München, Germany

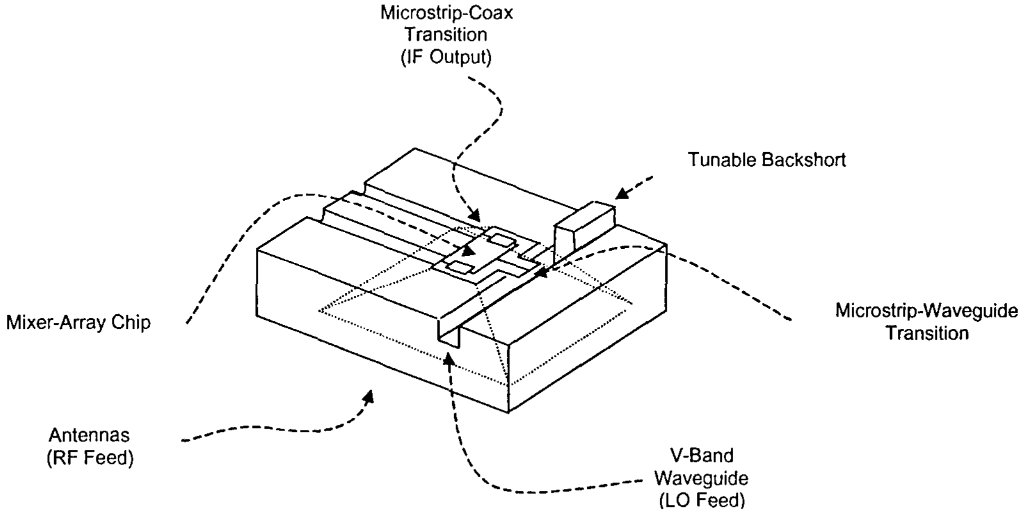

Fig. 1: Mixer block

different applications and at different frequency ranges [9], [10]. A lower pumping frequency simplifies the task of providing LO power (sources at about 70 GHz are more readily available than in the 150 GHz band). Furthermore, filtering of the image band is simplified as the need to match an LO signal lying between RF and image bands is eliminated.

I. ANTI-PARALLEL DIODES: DESIGN AND TECHNOLOGY

An equivalent circuit model has been used for the Schottky diodes. The linear part of the model was estimated from measurements and from the physical dimensions, and the non-linear part was based on measurements. This model is coherent with previous models electromagnetically de-embeded for such high frequency devices [11]. The values of diode parameters are shown in table 1.

Parameter	Value
I_{SAT} (saturation current)	$2x10^{-17}$ A
Ideality factor	1.15
C_{j0}	4.5 fF
R_s (series resistance)	7 Ω
ϕ_{bi} (built-in potential)	1.03 V
L_f (parasitic inductance)	10 pH

Tab. 1: Values of the diode model

The technological process provides minimised parasitics, which allow high frequency operation. Single diodes were included to be characterised on wafer, making possible a more accurate post-simulation. The anti-parallel diode pairs used as mixer elements are an evolution of those described in [6]. The air bridge is substituted by an anode finger which runs above a 1.5 to 2-µm thick passivation layer. This protects the diode further from physical damage. The ohmic contact, in turn, is realised from the front side in order to simplify the technological process. Contact pads are not necessary since the diodes are integrated on the microstrip line, eliminating an important contribution to parasitic capacitance.

Diode dimensions (1.3 µm anode diameter) are chosen to keep the parallel admittance of the junction capacitance (2·10-3 Ω-1) low with respect to that of the average junction resistance. Furthermore, the absence of backside contacts suppresses one of the most important contributions to parasitic capacitance.

Fig. 2 shows a picture of a fabricated pair of diodes taken with an optical microscope.

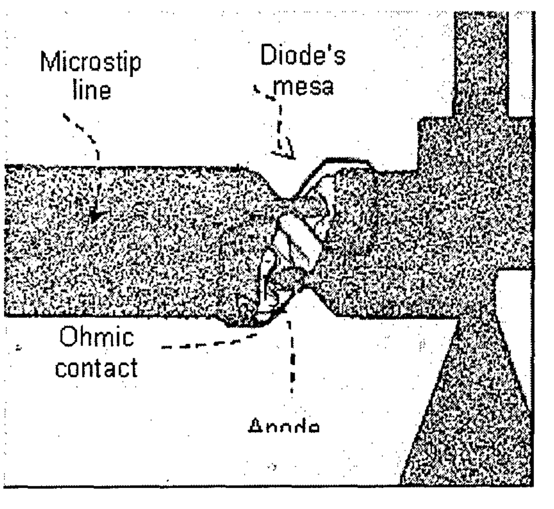

Fig. 2: Detail of the MMIC: Integrated Anti-parallel diodes

II. PLANAR PATCH ANTENNAS

Each channel receives plasma radiation in the band 144 to 153 GHz through a patch antenna coupled to the microstrip circuit by means of a slot on its ground plane. The antennas, about 400x400 µm2 nn size, are printed on a 150-µm thick fused quartz substrate using a thin-film technology. The radiation patterns calculated with the method of moments are typical for patch antennas. About 90 % of the radiated power is radiated for an angle of $\pm$ 45°.

III. Mixer Design

The goal of the design is to obtain the smallest conversion loss, with rejection of unwanted harmonics (fundamental mixing, image) and good isolation between ports.

Using the harmonic balance technique [12], the most suitable LO pumping power range to have almost matched impedance showed by the grounded diodes was estimated. The impedance of the grounded diode pair at 67.5 GHz is shown in figure 3 for LO power values between 1 and 20 dBm.

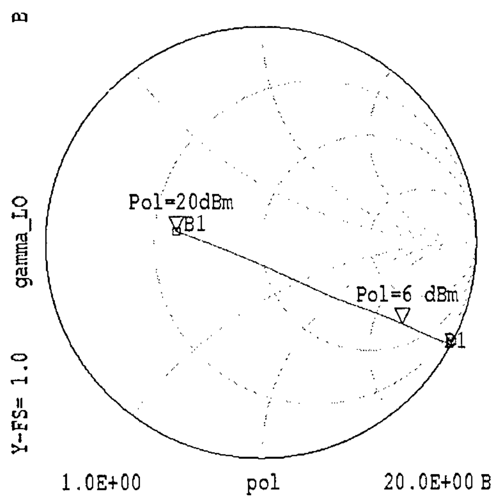

Fig. 3: LO impedance of the diode pair for several values of LO pumping power.

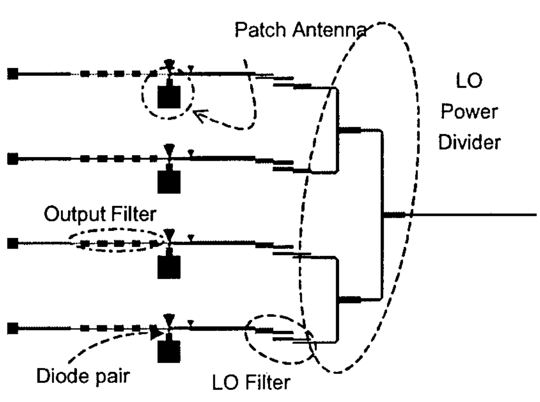

Fig. 4: Circuit layout

Performance of the mixer, especially in terms of conversion loss, is fixed by the design of the filtering and matching networks on each side of the diode pair [13]. The LO signal is injected through a microstrip structure which operates as LO filter and presents to the diodes a short circuit at IF and RF. Another structure on the other side acts as IF filter and LO short. The RF antenna is also coupled to this structure.

The IF signal is extracted from the RF side to increase LO-IF isolation.

The microstrip parts have been simulated with the standard equivalent circuit models, but also with an electromagnetic simulator using the method of moments to take into account additional coupling effects [14]. This is crucial to prevent unwanted changes of the desired characteristics, more important at higher frequencies.

Fig. 4 shows the layout of the MMIC, whereas Fig. 5 shows a fabricated structure.

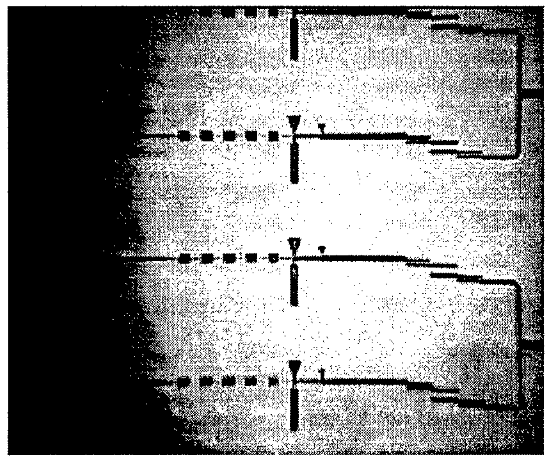

Fig. 5: Realised Microstrip MMIC

A procedure was applied to allow the simulation of RF power injection and the proper antenna impedance loading at the same time by using an Equivalent Large Signal Antenna. The reflection coefficient at the antenna input, previously obtained by electromagnetic simulation, is shown to the mixer circuit and at the same time RF power is flowing through towards the diodes, allowing the harmonic balance simulation of the mixer.

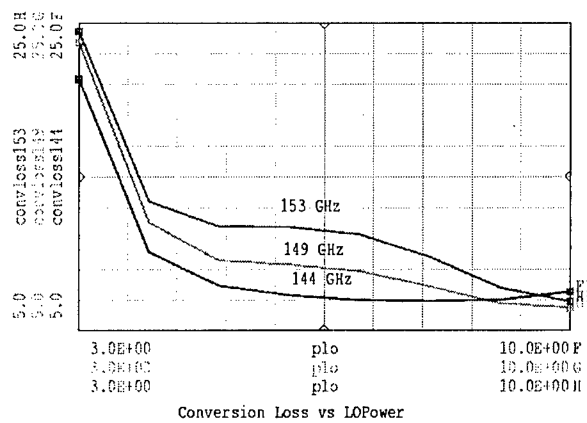

Fig. 5: Simulated conversion loss versus LO power for different values of RF frequency.

Conversion loss was evaluated in a single channel, using harmonic balance techniques in the whole RF band for several LO power values. The ripple across the RF band is less than 4 dB for each case.

Conversion loss saturate beyond 5 dBm pumping power per diode pair as it can be seen in figure 5 for three RF frequencies (lower, upper and middle band).

For LO available power ranging from 5 dBm to 10 dBm, best simulated values of conversion loss vary between 8 dB and 6 dB. This can be considered as an optimistic estimation.

Conversion loss versus IF frequency for several LO power values are shown in figure 6.

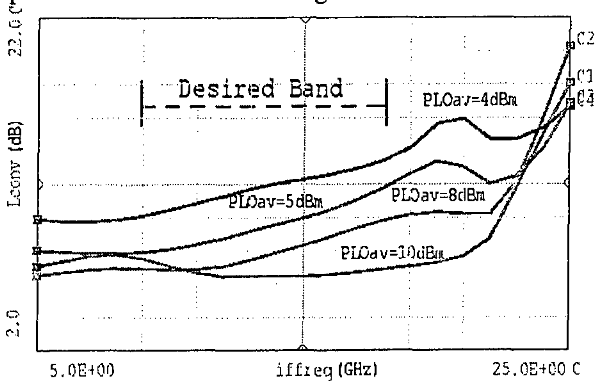

Fig. 6: Simulated conversion loss .

The goodness of the required shorts at IF, RF and OL frequencies at each side of the diodes was verified including the loading of the antenna and the LO power splitter.

Typical values of isolation between ports were also estimated. The LO-IF isolation is 31 dB. The LO power flowing towards the RF antenna is 41 dB below the injected LO level. The RF-IF isolation is shown in figure 9 for four values of LO available power. Because the antenna acts as an image filter, and also due to additional intended mismatching, down-converted image signal at the IF port is between 10 and 30 dB below the desired IF frequency. Optical filtering may improve image rejection if required.

The third-order interception point occurs for -6 dBm of output power: even or an optimistic value of –30 dBm of RF input power the third-order harmonic products at the output are more than 70 dB below the IF signal.

The double LO frequency at the output is negligible due to the anti-parallel diode properties to cancel it.

IV. Conclusions

A subharmonically pumped Schottky diode MMIC mixer has been designed for ECE plasma diagnostics applications.A Schottky diode high performance technology is used to allow fully integration on a single GaAs substrate, including also a patch antenna as RF port and an on-chip power distribution scheme. The design makes use of the anti-parallel diode structure advantages and it is strongly based on electromagnetic simulations of the planar microstrip structure. The first structures have been fabricated.

Acknowledgements.

The present work was partially financed by the European Commission through TMR contract number ERB FMRX CT-96 0050, and partially by the Max-Planck Institute for Plasma Physics at Garching, Germany.

References

[1] H.J. Hartfuss, T. Geist and M. Hirsch, "Heterodyne methods in millimetre wave plasma diagnostics with application to ECE, interferometry and reflectometry", Plasma Phys. Control. Fusion 39 (1997), 1693-1769.

[2] P.C. Liewer, Nucl. Fusion 25, 543 (1985).

[3] H.J. Hartfuss and M. Tutter, "Fast multichannel herterodyne radiometer for electron cyclotron emission measurement on stellerator W VII-A", Rev. Sci. Instrm. 55 (9), September 1985.

[4] N.Oyama et al, "Plasma diagnostics using millimetre wave two-dimensional imaging array", Fusion Engineering and Design 34-35 (1997), pp 407-410.

[5] .Cohn, J.E.Degenford, B.A.Newman."Harmonic Mixing with Antiparalell diode pair" IEEE trans. on MTT, Vol .23, pp 667-673, Aug.1975.

[6] C.-I. Lin, et al, "Anti-Parallel Planar Schottky Diodes for Subharmonically-Pumped 220 GHz Mixer". 10th Intl. Symposium on Space Terahertz Technology, Charlottesville, Virginia, 16-18 March 1999.

[7] M.V. Schneider. "Harmonically Pumped Stripline Down Converter," IEEE Trans. on MTT, vol.23, pp 271-275, Mar. 1975.

[8] M. Cohn, J.E. Degenford, B.A. Newman. "Harmonic Mixing with Antiparalell diode pair" IEEE trans. on MTT, Vol. 23, pp 667-673, Aug. 1975.

[9] T. Jamaji, H. Tanimoto, H. Kokatsu. "An I/Q Active balance Harmonic Mixer with IM2 cancelers and a 45 degrees phase shifter." IEEE Journal of Solid-State Circuits. Vol. 33, No 12, pp 2240-2246, Dec. 1998.

[10] C.I. Lin, M. Rodríguez-Gironés, A. Simon, J. Zhang, P.V. Piironen, V.S. Möttönen, H.L. Hartnagel, A.V. Räisänen, "Anti-Parallel Planar Schottky Diodes for Subharmonically-Pumped 220 GHz Mixer". 10th Intl. Symposium on Space Terahertz Technology, Charlottesville, Virginia, 16-18 March 1999.

[11] J. Zhang, P.V. Pironenen, V.S. Möttönen, J.T. Louhi, A.O. Lehto, A. Simon, C.I. Lin, A.V. Räisänen. "Wide-Band Equivalent Circuit of Quasy-Vertical Planar Schottky Diode for 650 Ghz Subharmonic Mixers". THz Workshop 97. Grenoble, France.

[12] Hewlett Packard's Microwave Design System, version B.07.10.

[13] A. Madjar, M. Musia, "Design and Performance of a x4 Millimeter Wave Subharmonic Mixer". Proc. of the 23rd European Microwave Conference, September 1993, Madrid, Spain.

[14] Hewlett Packard's MOMENTUM, ver sion A.02.58