A NEW MIXER FOR SENSOR APPLICATIONS

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Abstract

A new configuration of a gate mixer associated with a dual-polarized patch antenna was experimentally investigated for the first time. A gain of 5-7 dB was obtained at local oscillator (LO) power of -17 dBm at device terminals. The new configuration with low pumping power can significantly simplify the design of the LO sensor chain compared to the ordinary configuration which consumes 3-8 dBm per device.

Introduction

The question of reducing the LO power in a multisensor application is of great importance for the price, size and reliability of millimeter wave sensors .For a typical sensor with grid size of 16x16 and a LO power consumption of 3-8 dBm/device [1-6] the total LO power will exceed 1 W. If the sensor is working in W-band, the generation of such high amount of LO-power and the dissipation of the corresponding DC-power is not a simple problem.

A new configuration of a gate mixer associated with the patch antenna was successfully experimentally investigated. In order to get a deeper understanding and to simplify processing and measurements the sensor was manufactured as a scaled in frequency (1:8) model. After successful results has been obtained from the investigation of the scaled model at 10-12 GHz, a MMIC version will be manufactured at 94 GHz.

The Device Large Signal Modeling

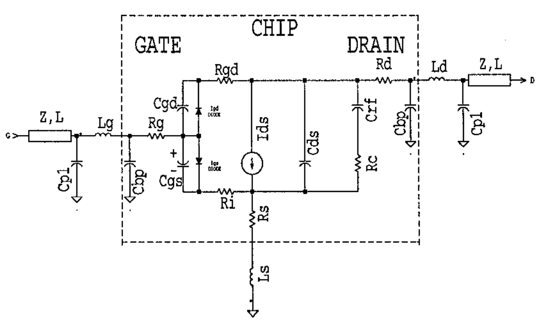

Fig. 1. Equivalent circuit of the HEMT.

A Mitsubishi HEMT MGF4317D was used for the mixer and the Chalmers nonlinear model [7,8] in the mixer simulations. The equation for the drain current of a FET device in our model is given by :

$$I_{ds} = I_{pk}[1+\tanh(\psi)](1+\lambda V_{ds})\tanh(\alpha V_{ds}) \qquad (1)$$

$$\psi = P_1\left(V_{gs}-V_{pk}\right)+P_2\left(V_{gs}-V_{pk}\right)^2+P_3\left(V_{gs}-V_{pk}\right)^3 \qquad (2)$$

$$V_{pk}(V_{ds}) = V_{pk0}+(V_{pks}-V_{pk0})\tanh(\alpha_s V_{ds}) \qquad (3)$$

$$\alpha = \alpha_r + \alpha_1[1+\tanh(\psi)] \qquad (4)$$

$$P_1 = P_{1sat}[1+\frac{B_1}{\cosh^2(B_2 V_{ds})}] \qquad (5)$$

where I_{pk} is the current and V_{pks} the gate voltage for peak transconductance at saturated drain voltages. V_{pk0} and V_{pks} are V_{pk} measured at V_{ds} close to zero and in the saturated region respectively. The large signal equivalent circuit is shown in Fig. 1 and the parameters of the model in Table 1.

Mixer Description

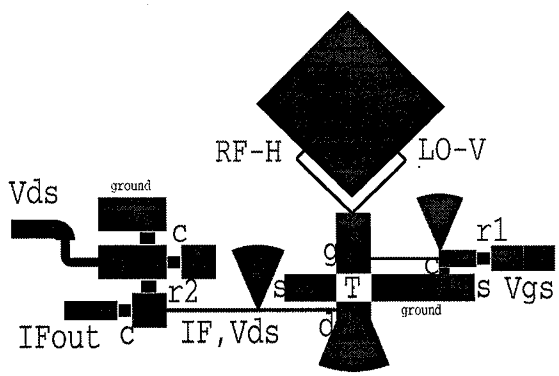

Fig. 2. Layout of the single cell.

The layout of a single element is shown in Fig. 2 and part of the sensor in Fig. 3.

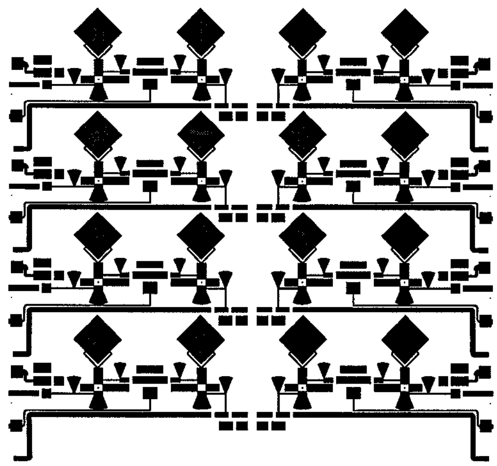

Fig. 3. Layout of the sensor

The RF and LO are applied in different polarizations and they are combined in the patch antenna.

The relatively high impedance of the patch antenna at resonance is transformed by using a quarter wave $\lambda/4$ transformer to the gate matching network. At the drain side a $\lambda/4$ low impedance radial open radial stub creates an RF short which is important for the proper operation of the mixer. The IF frequency is extracted from the drain side by using a simple resistive diplexer, RC-2. The distance between the patches is larger then $\lambda/2$.

The conversion gain can be estimated as [2]:

$$G_t = \frac{P_l(\omega_{if})}{P_{av}(\omega_{rf})} = \frac{g_{m\,\max}{}^2 R_l}{16\omega_{rf}{}^2 C_{gs}{}^2 (R_s + R_g + R_i)} \qquad (6)$$

The examination of the equation for the conversion gain (6) shows that in order to obtain higher gain from the mixer a device with higher transconductance and lower input impedance should be select ed. However gain higher than 8-10 dB is not desirable for the mixer then becomes very sensitive to the bias voltages and instabilities can appear.

Patch Antenna Design

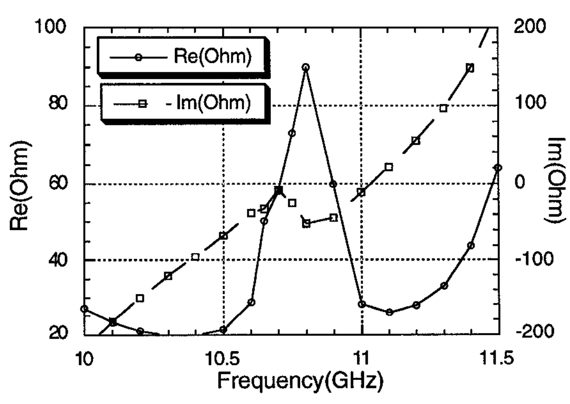

Fig. 4. Impedance for the dual patch antenna fed at the common RF and LO port.

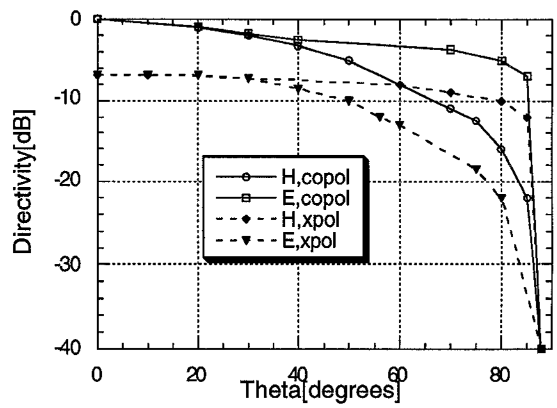

Fig. 5. Calculated E- and H-plane radiation patterns at 11.2 GHz. RF is reference. Responses were symmetric w.r.t. theta.

The rectangular patch antenna element has dimensions 7.6 mm x 7.9 mm and was manufactured together with the necessary diplexing circuitry on a standard (15 mil) substrate with relative permittivity 2.94. The design frequency was 11.16 GHz and 10.77 GHz for the RF and LO polarization respectively. The patch dimensions were determined iteratively by using the improved transmission line model [9] and by assuming that for each polarization the influence of the narrow feed line used for the other polarization was negligible.

Scattering parameters and antenna patterns for the dual polarization patch were then verified prior to manufacturing by using a commercial electromagnetic simulator. The calculated antenna impedance as a function of the frequency and the radiation patterns at 11.2 GHz are plotted in Fig. 4 and Fig. 5 respectively.

Conversion loss calculation

The LO and RF were combined in a commercial orthomode transducer XO-300, [10]. At the end of the transducer a horn XM-140 [10] was placed. The gain of this horn was calculated to be G_1 = 8.6 dB from the antenna pattern obtained from the manufacturer, Swedish Microwave AB. The gain of the patch antenna was calculated to be approximately G_2 = 5 dB. The measurement distance was R = 12 cm, which is just at the far-field limit using the criterion D^2/λ, where D is the maximum antenna diameter and λ the vacuum wavelength. The transmission parameter S_{21} for the microwave link is obtained by using the formula $|S_{21}|^2 = G_1\, G_2(\lambda/(4\pi R))^2$. At 11.2 GHz S_{21} is calculated: S_{21}=(8.6+5 -35) dB = -21.4 dB.

The conversion loss, L_C, can thus be obtained as:

L_C [dB] = P_{RF} [dBm] - P_{if} [dBm] - 21.4 dB.

where P_{rf} is the transmitted RF power and P_{if} is the detected IF power.

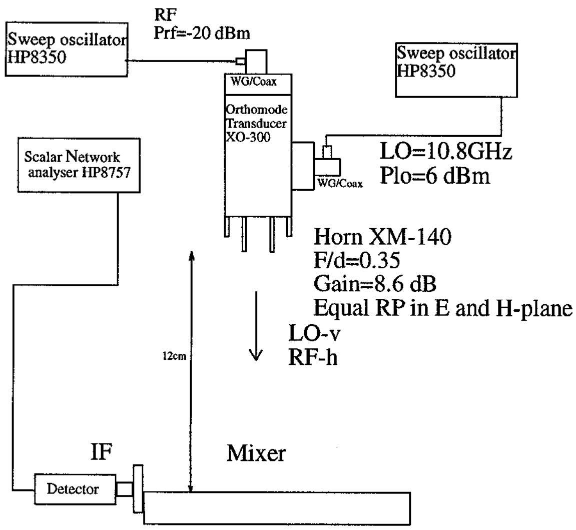

Fig. 6. Measurement set up.

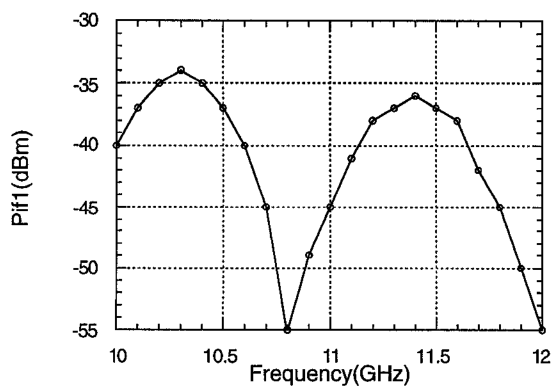

Fig. 7. Measured IF power vs. frequency. Vgs=-0.26V.

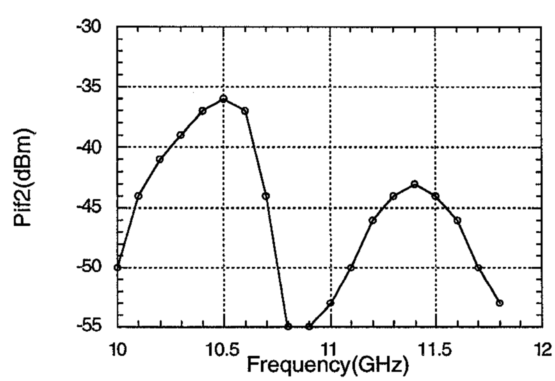

Fig. 8. Measured IF power vs. frequency. Vgs=-0.4V

Experimental results

The RF was kept at -20 dBm at the sweeper output and the IF signal was monitored by using a HP8757D scalar network analyzer. By changing the gate voltage, V_{gs}, it is possible to tune the mixer in two regimes:

a) V_{gs} =-0.26V: the response is quite symmetrical and measured P_{if1} is between -34 and -37 dBm, Fig. 7.

b) V_{gs} =-0.40V. The response is asymmetrical: the upper side band is suppressed, the sensitivity in the lower sideband is similar to the symmetrical case and measured P_{if2} is between -36 and -39 dBm , Fig. 8.

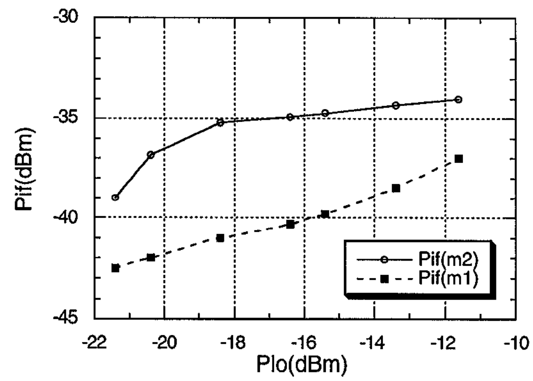

Fig. 9. Measured IF power vs. PLO calculated at the device terminal.

The minimum conversion loss is obtained as:

$L_{c,min}$ [dB] = -20 dBm - 21.4 dB - (-34 dBm) = -7.4 dB,

i.e. a conversion gain of more than 7 dB.
At LO power, referred to the output of the antenna, the mixer starts to saturate, Fig. 9, because of the high gain of the HEMT device :

P_{lo} = 4 dBm-21.4 dBm $\approx$ -17 dBm ,
This means that the mixer is working well with a very low received LO power at the device terminals. This is nearly a 20 dB reduction in the required LO power compared to competitive mixer types. This makes the proposed solution a very promising candidate for multisensor applications. The explanations for such low LO power requirements are:

1. The LO and RF are combined at the gate terminal with very small losses. In a conventional gate mixer the LO and RF are applied to the gate terminal through a ring filter or a directional coupler. This new approach greatly improves the effectiveness of combining the LO and RF at the gate terminal and allows the device properties to be exploited fully.

2. For the selected HEMT device the gate voltage required to switch the transistor on and of and to respectively switch the transconductance between max. and min. is very small-> 0.3V$\div$0.4 V. This further reduces the required pumping power.

Conclusions

A new configuration of a gate mixer associated with a dual-polarized patch antenna was experimentally investigated for the first time. A gain of 4-7 dB was obtained at local oscillator(LO) power of -17 dBm at device terminals. This is nearly a 20 dB reduction in the required LO power compared to competitive mixer types. The proposed solution is a very promising candidate for multisensor applications.

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Table 1. MGF4317D: V_{ds}=2V:

I_{pks} mA	V_{pks} V	V_{pk0} V	P_{1s} 1/V	P_{10} 1/V	P_2 1/V^2	P_3 1/V^3	λ 1/V	a_s 1/V	a_r 1/V
51	0.15	-0.07	2.5	3.5	-0.4	1.7	0.14	2.8	0.1
C_{gs0} fF	C_{gd0} fF	C_{ds} fF	R_g Ω	R_d Ω	R_s Ω	R_i Ω	L_g nH	L_d nH	L_s nH
280	40	110	2.0	2.8	1.7	5	0.46	0.45	0.07

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