A 23 GHz monolithic MESFET DRO as self-oscillating mixer

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Abstract

A monolithic GaAs 23 GHz dielectric resonator oscillator (DRO) was investigated as self-oscillating mixer in Doppler-radar applications. A maximum conversion gain of 10 dB at low oscillator power level and small frequency off carrier was calculated and measured. The associated minimum detectable signal (MDS) was determined to be between -130 dBm and -120 dBm.

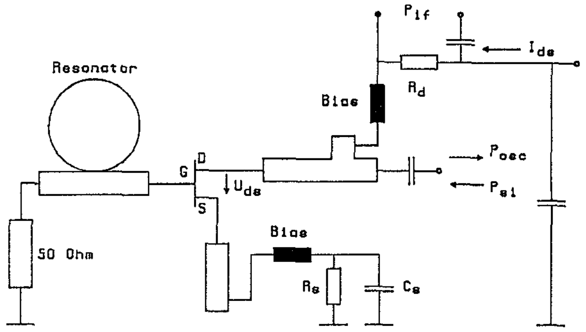

Fig. 1: Layout of MESFET DRO as self-oscillating mixer.

Introduction

Former investigations on self-oscillating mixers (SOMs) with Gunn or BARITT devices /1,2/ yielded simple and cheap heterodyne receivers and Doppler radar sensors. Compared to these devices a GaAs MESFET as active mixer can easily be integrated in a stripline environment /3/. Hence, a fully monolithically integrated MESFET SOM is potentially a low cost sensor for motion and proximity detection. In this work, conversion behavior of a 23 GHz monolithic self-mixing DRO is investigated.

Circuit description and fabrication

An oscillator topology with a series feedback configuration and an FET in common source operation as to see in Fig. 1 was chosen. The dielectric resonator is placed at the gate side of the transistor and the output port is at the drain side. The microstrip circuit was designed using small signal S parameters measured up to 30 GHz in a stripline test fixture and inhouse developed linear CAD software. The dielectric resonator coupled to the stripline was modeled as a resonant circuit. The length of the stub at the transistor source and the distance between the resonator and the gate were optimised to obtain a maximum negative resistance at the oscillator output port (drain). The output circuit was designed to match the oscillator impedance to a 50 Ohm load with respect to the oscillation condition. The technology used for the fabriation of the monolithic GaAs SOM has been published earlier /4/. The 7 mask fabrication process developed at Telefunken Electronic was performed by a metal organic chemical vapor deposition (MOCVD) for epitaxial growth. MESFET gate fingers were directly written by electron beam lithography. Typical Fmax values of about 90 GHz were obtained for transistors with 0.3 μm gate length and 4 x 50 μm gate width. The SOM circuit was fabricated on a 0.15 mm thick semiinsulating GaAs substrate. The transistor gate termination was formed by a microstrip line and an epitaxial 50 Ohm resistor. DC networks were consisting in a quarter wavelength stripline of 75 Ohm and a MIM capacitor for quenching spurious bias oscillations. RF output (i.e. signal input) was DC isolated by a further MIM capacitance inserted in the 50 Ohm output line. The dielectric resonator with a diameter of 2.3 mm and a dielectric constant of 37 was fixed on a carrier substrate adhered close to the monolithically integrated circuit.

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Mixer performance

To predict the conversion behavior of the investigated self-oscillating mixer, due to /5/ simplified expressions for the negative resistance of the oscillator, $-R_D$, and the dynamic I/V-characteristic of the FET have been used:

$$-R_D = R' (\Delta I_{DS} - A \Delta I_{DS}^2 - B \mid I_1 \mid^2) - R_l \qquad (1)$$

$$U_{DS} = R_0 (\Delta I_{DS} + C \mid I_1 \mid^2) \qquad (2)$$

ΔI_{DS} is the drain-source current above I_{sat} (I_{sat} is defined as the current at drain-source saturation voltage U_{sat}). R_l represents R.F. losses; R', R_0, A, B, C are constants to be determined using d.c. measurement results shown in Fig. 2. The gain at frequencies close to the carrier was calculated as followed /5/:

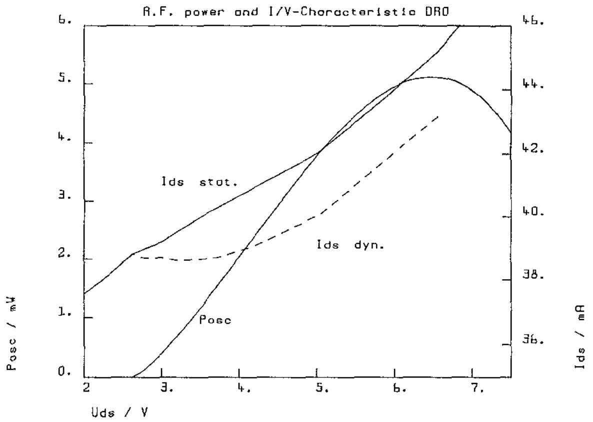

Fig. 2: R.F. power P_{osc} and drain-source current I_{DS} versus U_{DS}. The dashed line demonstrates the I/V-behavior of the oscillating MESFET.

$$G \mid_{f_d = 0} = \frac{1}{P_{osc}} \times \frac{2 R_L R_0 C^2}{R' B'} \times \frac{\frac{R_d}{R_0}}{\left[\frac{R_d}{R_0} + 1 \right]^2} \qquad (3)$$

with

$$B' = B + C \, \frac{1 - 2 A \Delta I_{DS}}{1 + \frac{R_d}{R_0}}$$

where R_L is the load resistance of the R.F. circuit (due to oscillation condition $R_L = -R_D$), Rd is the I.F. circuit termination and P_{osc} is the oscillator output power. The lines in Fig. 3 show the predicted gain as a function of

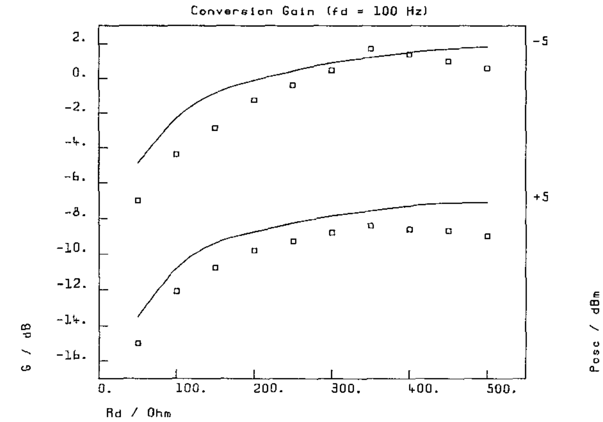

Fig. 3: Conversion gain G versus I.F. resistance R_d. Parameter is the oscillator output power P_{osc} (-5 dBm and +5 dBm, respectively). the solid lines are calculated, the dots are measured at f_d = 100 Hz.

R_d at P_{osc} = +5 dBm and P_{osc} = -5 dBm. Optimum matching of the demodulated signal is achieved at an I.F. resistance of about 350 to 500 Ohm, which is corresponding to the slope of the static current-voltage characteristic (see. Fig. 2). The conversion gain as a function of P_{osc} (R_d = 350 Ohm) is show in Fig. 4. Dots in Fig. 3 and Fig. 4 are measurement results obtained at

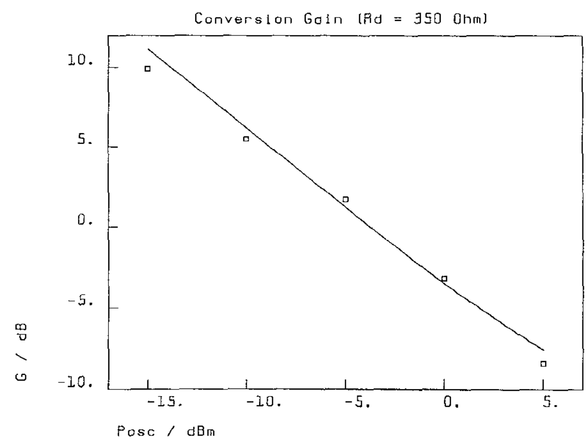

Fig. 4: Conversion gain G of the self- oscillating mixer as a function of P_{osc}. The solid line is calculated, the dots are measured at f_d = 100 Hz.

an oscillation frequency of 23.3 GHz and a signal frequency 100 Hz off carrier (the measurement setup used in this work to characterize the SOM has been described earlier /1/). It can be seen, that experimental and predicted values agree very well. Fig. 5 demonstrates the conversion gain versus I.F. frequency f_d from 100 Hz to 100 kHz. Highest gain of more than 10 dB could be measured at low f_d and small oscillator power level. A decrease of G with increasing f_d may be explained by thermal effects. A similar behavior has been observed at BARITT SOMs /2/.

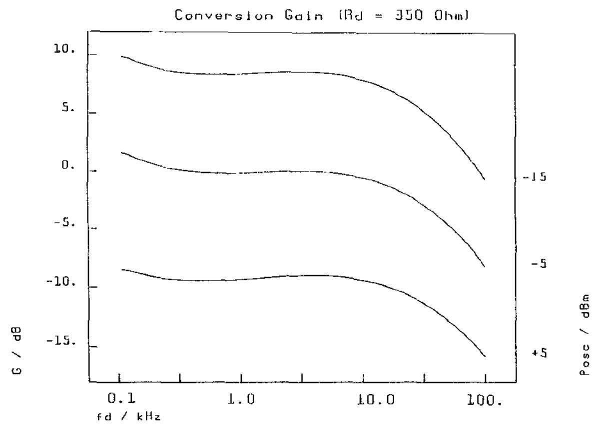

Fig. 5: Measured conversion gain G as function of intermediate frequency f_d (R_d = 350 Ohm). Parameter is P_{osc}.

The most important measure of the self-oscillating mixer performance is the minimum detectable signal (MDS) containing the conversion characteristics as well as the I.F. AM noise P_N /2/:

$$MDS = \frac{P_N}{G} \qquad (4)$$

MDS measurements shown in Fig. 6 (R_d = 300 Ohm, bandwidth = 1 Hz) indicate values of between -130 dBm and -120 dBm depending on frequency off carrier f_d at weak P_{osc} (-20 dBm).

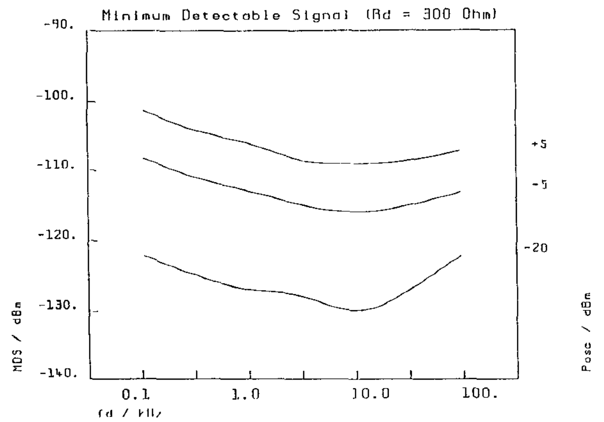

Fig. 6: Minimum detectale signal MDS versus intermediate frequency f_d (R_d = 300 Ohm). Parameter is P_{osc}.

These values are clearly better than those of Gunn or IMPATT SOMs /1/. Taking the lower output power of the MESFET DRO into account, the mixing sensitivity in Doppler applications may become similar to that of a Gunn SOM.

Conclusion

A 23 GHz monolithic MESFET DRO has been investigated as self-mixing local oscillator at the intermediate frequency range of 100 Hz to 100 kHz. Conversion gain predictions obtained by a simplified impedance model (using only power, d.c. current and voltage measurements) could be verified experimentally leading to a gain of more than 10 dB at signal frequencies close to the carrier. A minimum detectable signal (MDS) of -130 dBm could be achieved. These results favour the application of MESFET SOMs as low cost monolithically integrated Doppler sensors.

References

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Acknowledgement

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