A 2 GHz ENHANCEMENT MODE GaAs DOWN CONVERTER IC FOR SATELLITE TV TUNER

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ABSTRACT

A fully integrated 2 GHz down-converter IC has been designed and fabricated for satellite TV application using an enhancement mode GaAs foundry process. Its internal oscillator covers a 1.2 GHz bandwidth that allows to receive the extended satellite TV band from 950 MHz to 2 Ghz. The LO power leakage is greatly reduced as compared to a discrete circuit : it is about -40 dBm at the RF input and less than -30 dBm at the IF output. This IC operates under a single 5 V supply voltage and its performance is an outstanding trade-off between noise, linearity, power consumption and simplicity of implementation. It is encapsulated in a standard low cost plastic package and is already available for sampling.

INTRODUCTION

Much attention has been paid since a few years to the integration of the mixer/oscillator circuit of the satellite TV tuner, using Si-bipolar or depletion mode GaAs MESFET technologies [1]-[3] . Integration is partly dictated by the market trend which is to reduce the size and the number of components in the equipments. Another reason is that an integrated mixer/oscillator can takes advantage of a balanced structure with low inherent LO leakage, and achieve therefore a much superior radiation performance than a discrete circuit.

The 2 GHz mixer/oscillator IC presented in this paper has been fabricated using the enhancement mode GaAs process ER07AD available at the Philips Microwave Limeil foundry. Enhancement mode FETs have low current consumption, about 2 to 3 times less than depletion mode FETs. Their large signal handling capability is not as good as depletion mode devices but is sufficient however for most microwave applications, and comparable to that of advanced Si-processes. Due to a better noise performance, enhancement mode GaAs FETs have however a superior dynamic range than Si-bipolar transistors. These features have allowed to reach an outstanding trade-off between power consumption and dynamic range.

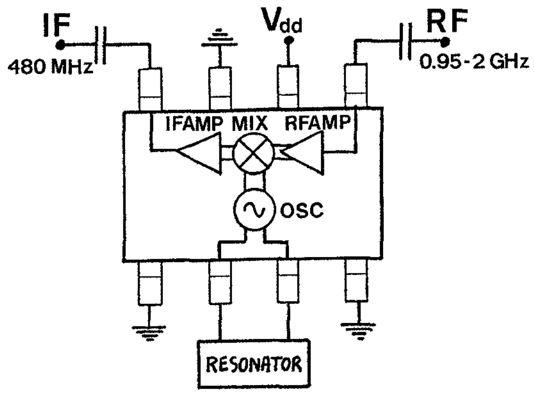

Figure 1. Block diagram of the down-converter IC.

CIRCUIT DESIGN

The block diagram of the down-converter is shown in Figure 1. The IC consists in a RF amplifier (RFAMP), a double balanced mixer (MIX), a dual phase oscillator (OSC) and an IF output stage (IFAMP). It offers single ended 50 ohms matched input/output that simplify its implementation.

The RF amplifier is a common source stage with voltage shunt feedback to achieve low input impedance. The feedback loop biases the transistor and stabilizes the operating point.

The mixer is a double balanced Gilbert cell with a differential RF stage having one input grounded. It delivers two balanced IF signals which are taken on the drains of the mixing transistors.

As the output impedance of the mixer is quite high, the first stage of the IF amplifier is a source follower. The IF signals are then combined into a low output impedance push-pull stage.

The oscillator is of the multivibrator type. The drains of the differential pair are cross-coupled to the gates making a positive feedback. This structure has been

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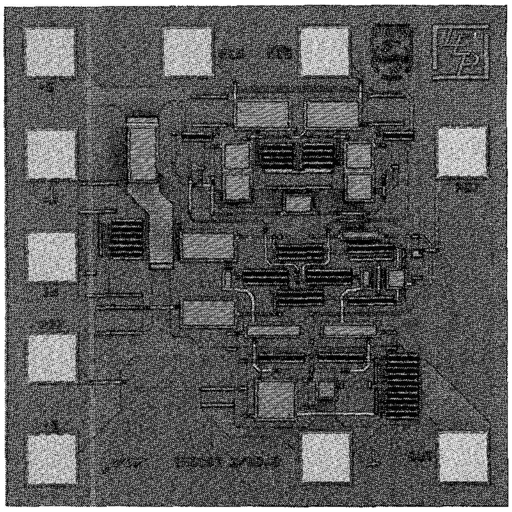

Figure 2. Photograph of the down-converter IC.

chosen for its high negative conductance to current ratio. The differential negative conductance is about -2.5 mS to -3 mS and is quite flat over a broad band. The oscillator tank circuit is not integrated and consists of a printed circuit and two SMD varicaps. The balanced signals delivered by the oscillator are fed to the mixer via a source follower as buffer stage.

In order to minimize intermodulation, the gain distribution has been optimized and the conversion gain has been limited to less than 10 dB, by reducing in particular the gain in front of the mixer.

FABRICATION

The IC has been fabricated using the fully calibrated 0.7 μm enhancement mode GaAs MESFET process ER07AD available at the Philips Microwave foundry in Limeil, France. This process is especially suitable for low power L band to C band mixed analog/digital applications [4], [5] . It offers sizeable digital integration capacity (up to 1000 gates) while keeping excellent analog performance (minimum noise figure of 0.8 dB at 2 GHz), high breakdown voltage, and normally-on areas for power. It has an f_t of 15 GHz, the threshold voltage is $V_t = +175$ mV and the drain current is 70 mA/mm at $V_{GS} = 0.7$ V. A photograph of the down-converter IC is shown in Figure 2. Its size is 0.84 mm x 0.84 mm. The IC is encapsulated in a standard 8 pin low cost package of which 3 pins are used for grounding. It is already available for sampling.

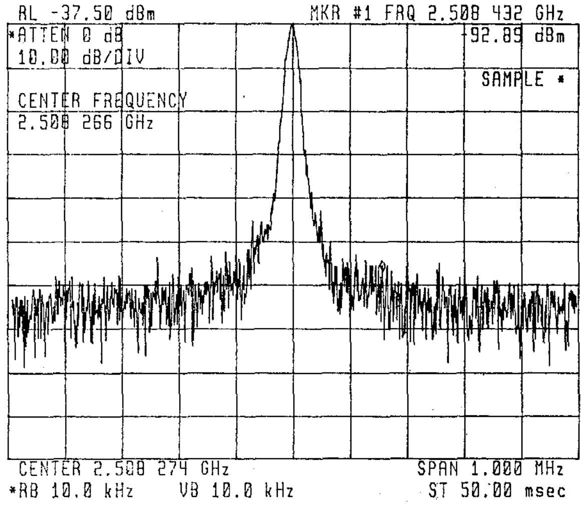

Figure 3. Oscillator noise spectrum at 2.5 GHz.

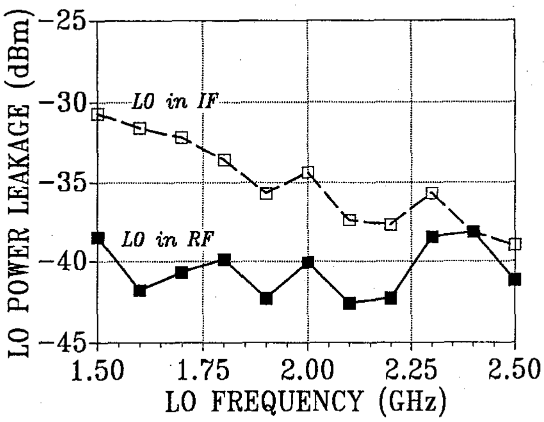

Figure 4. LO leakage at RF and IF ports.

MEASUREMENTS

A first set of measurements has been carried out in order to verify the oscillator bandwidth and to determine the performance of the mixer driven by the internal oscillator. The oscillator bandwidth is 1.2 GHz from 1.4 to 2.6 GHz using varicaps with a high capacitance ratio and a minimum capacitance of about 0.7 pF. This wide tuning capability allows to receive the extended IF satellite TV band (950 MHz-2GHz). The frequency linearity is about 1% over a 1 GHz band and the phase noise ranges between -95 and -100 dBc at 100 kHz frequency offset.Figure 3 shows an example of oscillator spectrum measured at 2.5 GHz. The LO power leakage is very low. Figure 4 shows that it is less than -30 dBm at the IF port and about -40 dBm at the RF port in the 1-2 GHz band.

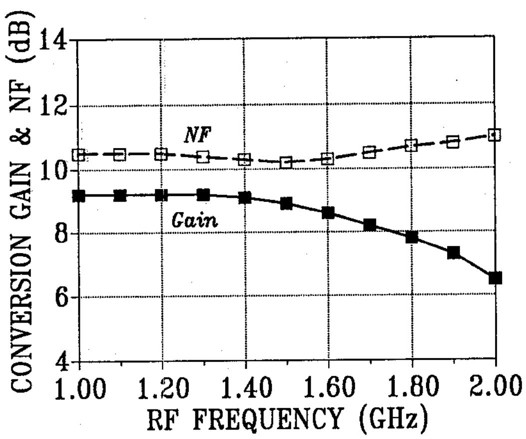

Figure 5. Conversion gain and SSB noise figure frequency characteristics.

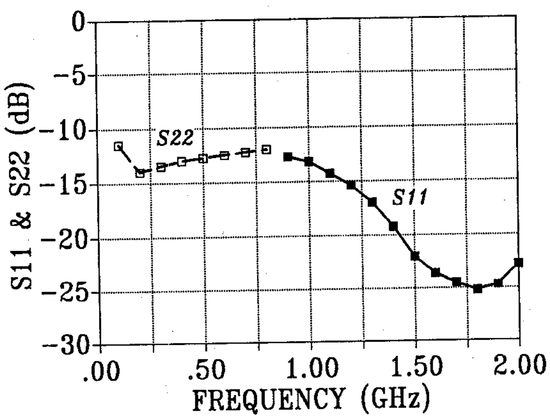

Figure 6. Input/output matching characteristics.

The mixer performance has been measured at IF = 480 MHz. Typical conversion gain and SSB noise figure characteristics are shown in Figure 5. The gain is about 9 dB at 1 GHz and 6.5 dB at 2 GHz whereas the SSB noise figure ranges between 10 and 11 dB. The input/output matching characteristics are shown in Figure 6. The input matching is better than -13 dB over the 1-2 GHz band and the output matching better than -10 dB from 0.1 to 0.7 GHz. The large signal performance has been determined by measurement of the output power and of the intermodulation distorsion. The output power at 1 dB compression gain is -1 dBm at 1 GHz (Figure 7). The input third order intercept point is almost constant over the 1-2 GHz band and equal to -2 dBm. This leads to a suppression of third order products of about 45 dB at an input level of -25 dBm. This good performance is obtained with a very low power consumption of about 140 mW under 5 Volts supply voltage.

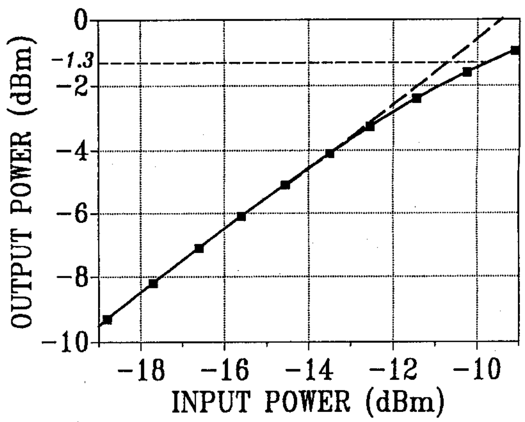

Figure 7. Output power characteristic at 1 GHz.

Systematic measurements have been then performed in order to determine the min/max values of the main electrical parameters. 95 circuits issued from 2 wafers have been tested. Only 5 have been eliminated that were not working or were completely out of the specifications. For convenience, an external generator has been used in these measurements to supply the LO signal. The oscillator pins for connection to the resonator have been used as input for the external signal. The power level has been set in order to get about 1 Volt peak differential voltage at the oscillator pins. The performance measured in these conditions is very similar to that of the mixer driven by the internal oscillator. This is an indication of the good operation of the internal oscillator. The measurement results are summarized in Table 1. The mean gain is 9 dB at 1 GHz and 6.2 dB at 2 GHz. The standard deviation is about 1 dB at both frequencies. Similar spread is observed on the output power at 1 dB gain compression. Parameters mostly determined by the RF amplifier, such as noise figure and input matching, show lower spread. This is probably due to the stabilization provided by the voltage shunt feedback used in this stage. The reproducibility of the LO power leakage with respect to its mean value is also noticeable.

parameter	mean value	std dev
gain at 1 GHz	9 dB	1 dB
gain at 2 GHz	6.2 dB	0.9 dB
NF(SSB) at 1 GHz	10.5 dB	0.4 dB
S11 at 1 GHz	-13.6 dB	0.3 dB
Pout(-1dB) at 1 GHz	-1.6 dBm	1 dBm
LO in RF at 1 GHz	-39 dBm	1.2 dBm
LO in IF at 1 GHz	-30.4 dBm	1.7 dBm

Table 1. measurement results of 90 circuits.

CONCLUSION

The present 2 GHz down-converter IC is compact, dissipates very low power and exhibits good performance under 5 Volts supply voltage. It is mounted into a low cost plastic package and is already available for sampling. These results clearly demonstrate that the enhancement mode GaAs MESFET technology available at Philips Microwave, Limeil, brings an efficient solution to integration requirements in low power commercial microwave applications.

ACKNOWLEDGFMENTS

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