A 3 CHIP GaAs DOUBLE CONVERSION TV TUNER SYSTEM WITH 70 dB IMAGE REJECTION

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ABSTRACT

A 3 chip VHF-UHF TV tuner system has been implemented with a 0.7 µm MESFET GaAs technology. The system based on the double frequency conversion method consists in an up-converter (IF_1 = 1.9 GHz), a smooth filter and an image rejection down-converter (IF_2 = 35 MHz); it exhibits 30 dB of conversion gain and 70 dB of image frequency rejection throughout the VHF-UHF band.

INTRODUCTION

Today, the main signal processing functions in TV receivers are fully integrated. Audio and Video informations are extracted from the transmitted signal around 35 MHz. At this frequency, most of the Si processes can be successfully used to meet the required specifications.

On the other hand, the conversion of the incoming VHF-UHF signals down to the 35 MHz band without significant degradation of S/N ratio, low intermodulation, and drastic frequency image rejection ($>$ 60 dB) is highly difficult to fully integrate and conventional front-ends are routinely fabricated by hybrid techniques (discrete components)associated with expensive trimming procedures.

There has been some attempts to try and integrate this function : with a Si process, good mixer/oscillators chips, operating up to the UHF band have been successfully demonstrated (1). On the other hand, GaAs MESFET technologies have been used to demonstrate the feasability of a double conversion system (2), and that of a direct conversion IC (3). Recently, a one-chip image rejection down conversion IC has been reported (4). In this latter case, however, some trimming was necesary to maintain the rejection level (40 dB) throughout the VHF-UHF band.

In this paper, we take advantage of the double conversion concept, associated with image rejection mixers to reach a high level of image rejection (70 dB) without any channel-dependent trimming. Moreover all functions have been integrated, including the voltage controlled oscillators (VCO's) so that the system does not need external components any more.

TV TUNER SYSTEM ANALYSIS

Either in Si or GaAs technologies, high selectivity filters are tricky to fabricate because of the poor quality factor of self-inductances.

Therefore, quadrature conversion associated with Image Frequency Rejection Mixers (IFRM) has been extensively investigated. Though theoretically infinite, the rejection level is, in practice, limited by the phase errors and/or gain mismatches between the two branches of the IFRM system. Within a direct down-frequency conversion, these errors have to be compensated for, each time the selected input channel is changed.

In order to overcome this drawback, we have resorted to an up-conversion (at IF1 = 1.9 GHz) followed by a quadrature down-conversion (at IF2 = 35 MHz) (figure 1).

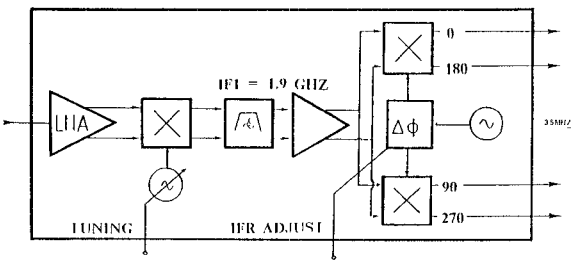

Figure 1 : Monolithic TV tuner - Schematics

The advantages are :

- The relative tuning range of the first conversion oscillator is strongly reduced with respect to a simple down conversion approach (1.9 GHz - 2.8 GHz, say 0.56 octave as compared to 3.2).
- The image frequency for the second conversion is fixed (IF1 - 70 MHz) and some prefiltering can be carried-out at IF1.
  This smooth prefiltering is made with conventional integrated LC filters and provides a gain of 20 dB and a rejection of 4 dB at 70 MHz off the center frequency (1.9 GHz). Last but not least :

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- As the IFR mixers operate at a fixed frequency, the quadrature Phase Shifter can be narrow-band (around IF1 - 35 MHz), and can be electrically adjusted in order to preset the optimum operation.

CIRCUIT DESIGN

Three chips have been developed :
- A Low Noise Amplifier (LNA) + Mixer + VCO + 50 ohm output matching (up-conversion chip),
- A two stage passive filter with 50 ohm output matching (Fc = 1.9 GHz : rough pre-filtering at IF1).
- IFRM + Local Oscillator (at 1.865 GHz) and Phase Shifter (down conversion with image rejection).

These IC's have been measured separately and finaly combined to form a complete tuner system.

The LNA is a broadband amplifier (40 MHz - 2 GHz) with 25 dB gain and AGC. 75 ohm input impedance matching is achieved via a biasing loop ; differential operation is used as soon as possible and a voltage feedback improves the flatness of the gain-frequency characteristic.

The same VCO type is used for both up and down conversion. It consists of a multivibrator loaded with parallel resonant LC network. The frequency tuning is ensured by 2 varactors (figure 2) controlled by a voltage ranging from V_{DD} down to ground.

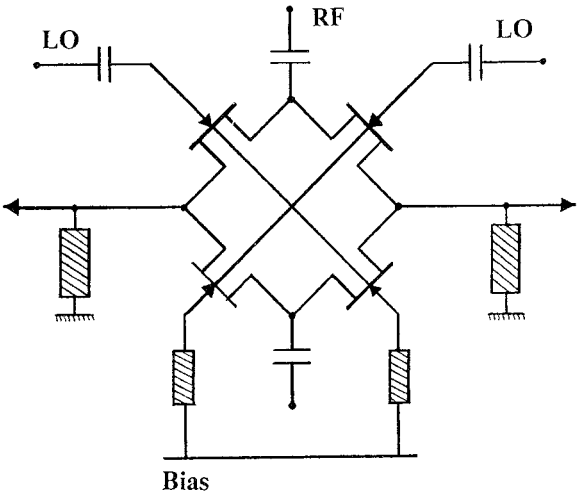

Figure 2 : Voltage controlled oscillator

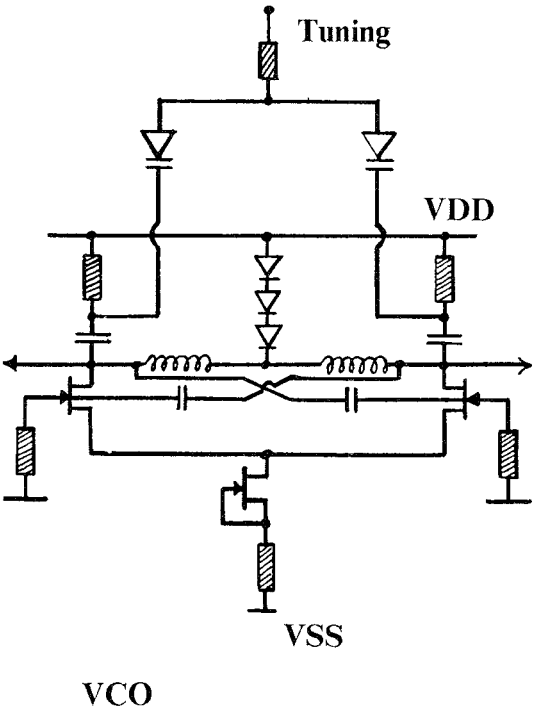

Figure 3 : Ring mixer

The "ring" configuration has been chosen for the mixers (figure 3) because it exhibits very low 1/f noise (no DC current) in addition to a reduced power consumption.

The 0-90 degrees Phase Shifter is based on R-C all-pass network. The values or R and C are chosen for optimum operation at IF1 - 35 MHz (say here 1.865 GHz). Only one trimming voltage is provided to optimize the rejection level one time for ever. This trimming is performed throught a 10 µm MESFET used as a voltage controlled resistor in parallel with the resistor of the RC network.

The IF_1 filters are narrow band differential amplifiers loaded by parallel resonant L-C networks. Positive feedback is used to increase the gain and selectivity though main of the image rejection is achieved by the IFRM.

The IFRM IC provides the four phase of the video signal at 35 MHz. A LF 0-90 degree combiner has to be used to effectively achieve the image rejection. This function is implemented on the subsequent silicon chip.

PROCESS

The three ICs have been fabricated with a .7 µm Depletion mode MESFET process. For a Vt of - 3 V, IDSS is 300 mA/mm with a peak transconductance of 180 ms/mm. MIM capacitors with 400 pF/mm^2 have been used.

MEASUREMENTS

A first process run with non optimum electrical characteristics of the MESFET has yielded the following results :

1. Up-converter :
The power gain in a 0.1 - 1 GHz frequency range is typically 18 dB (.1-1 GHz) associated with a noise figure of 12 dB (figure 4). The LNA provides 25 dB while -7 dB is lost in the mixer. The intermodulation product (IP3) is -8 dBm. This corresponds to a 1 % crossmodulation level of 75 dB µV.
The frequency band of the VCO is 1.9 - 2.7 GHz (achieved by a tuning voltage ranging from 0 V to 6 V) so that any channel in the VHF-UHF band can be up-converted to 1.9 GHz (IF_1).

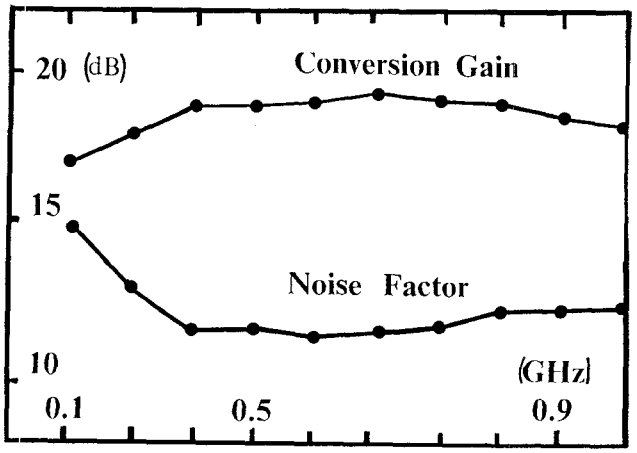

Figure 4 : Up-converter performances

2. Narrow band amplifiers
The power gain is 20 dB at 1.9 GHz with a rejection level of 4 dB at 70 MHz off the center frequency.

3. IFRM, LO and Phase Shifter
The conversion gain is -10 dB at RF = 1.9 GHz and LO = 1.865 GHz. The image rejection level is typically 50 dB (rough trimming) and can reach the noise floor of the spectrum analyzer (70 dB) when accurately trimmed.

4. Complete system
The three chips have been connected together on an alumina substrate (figure 5).
The total conversion gain is 30 dB and the rejection level is more than 60 dB throughout the VHF-UHF band (figure 6) with only one preliminary trimming at 500 MHz. The limited rejection band (50 dB at ± 4 MHz) is due to the unperfect 0-90° combiner. The trimming voltage sensitivity is in the order of ± 10 mV to maintain the rejection level.

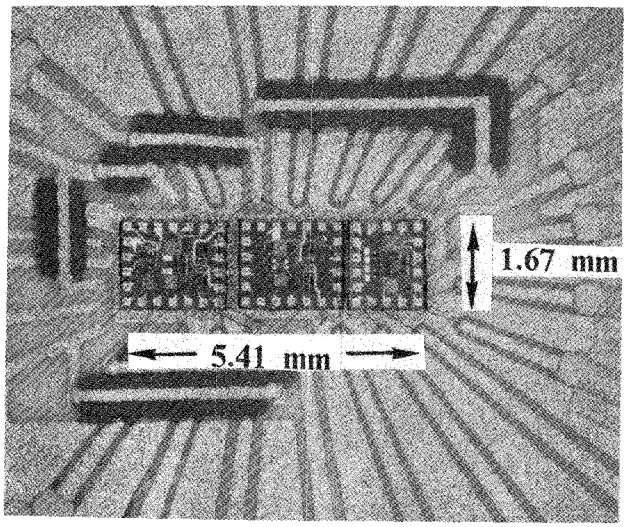

Figure 5 : 3 chip tuner system

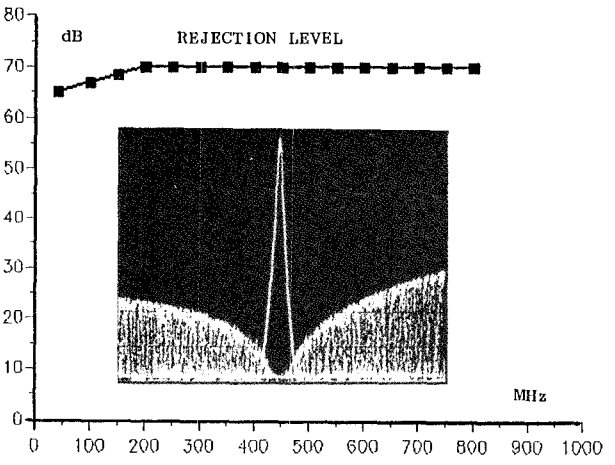

Figure 6 : Image frequency rejection

CONCLUSION

We have demonstrated that the double conversion concept (up/down) associated with quadrature down conversion was a viable solution to solve the image frequency rejection problem within an integrated circuit. The 3 chips system that we have developed is already a practical solution for modern TV tuners ; the measured performances indicate that a "high-spec" fully monolithic approach is possible. Only the noise figure is still to be improved but a recent publication (5) indicates that a NF of less than 2 dB is not out of reach with GaAs.

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