AN ULTRA BROADBAND UPCONVERTER CIRCUIT

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ABSTRACT

An ultra broadband upconverter MMIC has been designed, realized and measured using a 0.25 µm PHEMT process on GaAs [1]. It contains a switch, amplifiers, a step attenuator, filters, and mixer. The input frequency band is 2 - 12 GHz and the output frequency band is 8-18 GHz. The input signal, selectable using a switch, is amplified and converted from 2-12 GHz to 18-8 GHz. An attenuator is used to increase the dynamic range of the circuit. Measured performance shows full functionality with an overall gain better than 30 dB and with a noise figure of 5 dB. The work was part of a CEPA project.

INTRODUCTION

MIMOSA is a project with an overall aim to develop low cost compact modules for a wide range of applications such as radars, electronic warfare and military communications. Part of this work is to develop an upconverter multifunction chip with wide bandwidth, high gain and high dynamic range.

This paper presents the design and measurements of the ultra broadband upconverter multifunction chip, MUSIC (Mimosa Upconverter Single Integrated Circuit).

REQUIREMENTS AND BLOCK DIAGRAM

The block diagram and target specification for MUSIC is shown in Figure 1. Two design iterations were performed. During the second iteration, minor corrections were done and level shifters (marked "4" in Figure 2) added for simpler control of switch and attenuator. The amplifiers were replaced with single supply amplifiers for easier biasing. Coating one of the two wafers in the second iteration, with BCB (Bisbenzo-Cyclobuten), was performed to analyze the influence of BCB on circuit performance.

Specification	Target
Frequency range in [GHz]	2-12
Frequency range out [GHz]	18 -8
Noise figure [dB]	< 6
Gain [dB]	33 ± 4
Gain control [dB]	30 ± 2
P_{1dB} (input, dBm)	> -38 or -8
In- and output matching [dB]	< -10

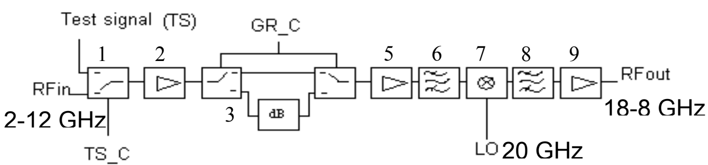

Figure 1: Target specification (top) and block diagram (bottom).

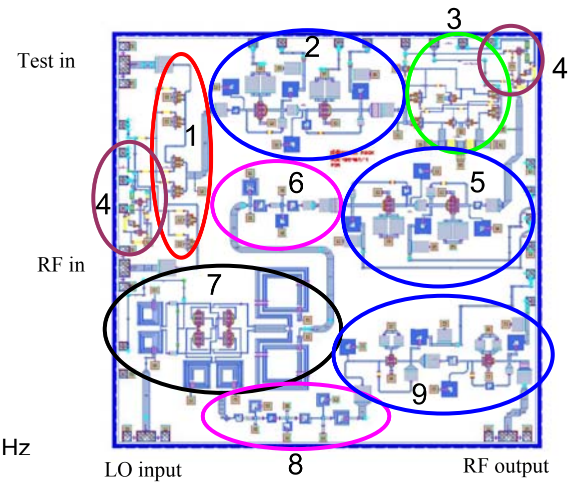

Figure 2: Layout of MUSIC (second iteration) Chip size: 4.5 X 4.5 mm.

SUB-CIRCUITS

Amplifiers

There are three amplifiers in MUSIC (marked '2','5' and '9' in Figure 2), two in front of the mixer (2-12 GHz) and one at the output (8-18 GHz). The architecture is almost identical for the three amplifiers and consists of two stages with a resistive feedback loop to get sufficient gain over the full bandwidth. This design was chosen due to low noise figure and wide bandwidth [2]. The topology of the amplifiers is shown in Figure 3.

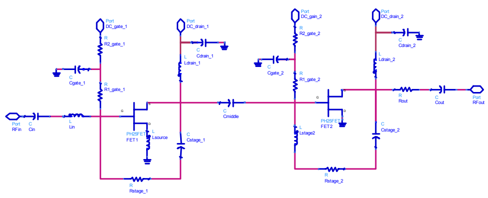

Figure 3: Topology of amplifiers.

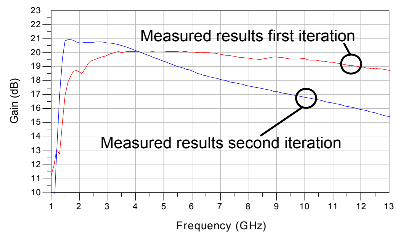

Figure 4: Results for the 2-12 GHz amplifiers (no BCB).

To improve input matching and stability, an inductor was added on the source of the first stage. The inter-stage matching network is simply a capacitor for DC isolation. Using an inductor in the feedback loop for the second stage increased the gain at the higher end of the frequency band. For the output amplifier (8-18 GHz), the series inductor at the input was replaced by an inductor to ground to get better input match. Also, an inductor was added in series in the inter-stage matching. The current consumption was 30 mA for the first and 40 mA for the second stage with 3V drain voltage. In the second design iteration, the amplifiers were changed to a single supply design with the same currents but a 5V drain voltage.

The amplifiers for the 2-12 GHz band had a gain of 20 ± 1 dB (Figure 4), with a noise figure better than 2.7 dB. The amplifier for the 8-18 GHz band had a gain of 17.5 ± 1 dB. For the second iteration, the amplifiers for the 2-12 GHz band got a 5 dB gain slope due to improper modeling of the source components. Using ADS Momentum to better simulate the source load, the measured result could be recreated in the circuit simulator. Gain for the output amplifier (8-18 GHz) was 16 ± 1 dB.

Switch

A switch function was used both at the chip input and in the attenuator block, the former in order to choose between the RF signal and a test signal (marked '1' in Figure 2) and the latter in order to insert a 30 dB attenuation of the signal after the first LNA block (if required). A switch configuration that had low insertion loss and high isolation for a wide bandwidth was chosen [3]. Measurements on the switch showed an insertion loss better than 1.4 dB and isolation better than 30 dB over the 2-12 GHz frequency band.

Attenuator

The attenuator block was realized by a double pi-attenuator and is marked '3' in Figure 2. It consists of two switches (each switch built by four FET:s), switching between two different paths, one "0-dB" attenuation path and one "30-dB" attenuation path. The "30-dB" attenuation path was realized by the pi-attenuator block consisting of five resistors made of GaAs. Measurements showed a relative attenuation of 30 ± 0.5 dB with an insertion loss of 2 dB over the 2-12 GHz frequency band.

Mixer

For the mixer (marked '7' in Figure 2), there is an overlap between the frequency band for RF (2-12 GHz) and IF (8 -18 GHz), which makes it hard to suppress unwanted signals. For this reason it was decided to use a double balanced resistive FET mixer in a star configuration [4]. A coiled Marchand type balun was used for all three baluns. This gave sufficient bandwidth for the LO and IF signal, but not for the RF. Therefore a new balun was designed for the second design iteration, also a Marchand balun, but consisting of three coupled lines. Capacitors were added to compensate for different phase-velocity for even and odd modes. A coupled line was added to the output to represent a 100 Ω line for odd mode.

The conversion gain for the first iteration was 10 ±2 dB (reduced bandwidth 8-16 GHz) and showed good agreement with simulated results as shown in Figure 5. Unfortunately, the second iteration design did not show the same correspondence (Figure 6). However, losses were reduced by 7 dB in the upper part of the band (low RF input frequency) compared with results for the first design iteration.

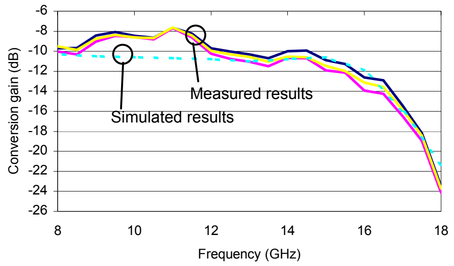

Figure 5: Measured and simulated conversion gain for the first design iteration (3 circuits).

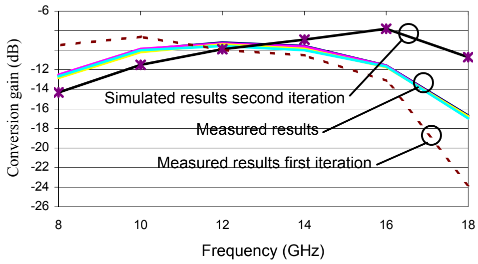

Figure 6: Measured and simulated conversion gain for the second design iteration (3 circuits, no BCB).

Filters

There are two filters within the chip, one on each side of the mixer. These are meant to help reduce unwanted signals and spuriouses. The design goals were set rather moderate and the filter structures were kept simple. Both filters are Chebyshev band pass filters with three and five poles respectively (marked ‘6’ and ‘8’ in Figure 2). The suppression at 1.2 GHz was 13 dB with an insertion loss of 2.7 dB (RF filter, “6”). The suppression at 7 GHz and 20 GHz was 7.5 dB and 3.5 dB respectively, with an insertion loss of 4.4 dB (IF filter, “8”). For the second design iteration the IF filter was adjusted, and the suppression at 20 GHz was improved to 15 dB (17 dB with BCB).

THE CHIP

First run performance

Figure 7 and Figure 8 show the results for MUSIC. The gain varies from 36 dB to 43 dB in the frequency band 8-17 GHz, which is acceptable. Between 17-18 GHz the gain drops rapidly, so the target specification for full bandwidth is not met in this frequency band. This is due to the limited bandwidth of the RF-balun in the mixer. There was however a good resemblance between the measured performance and simulated performance. The result of temperature measurement shows a gain variation of 2 dB for a temperature interval between (–10°) – (+40°). The noise figure (NF) is better than the target, NF < 4.5 dB (target NF < 6 dB). The simulated noise figure was < 4.1 dB.

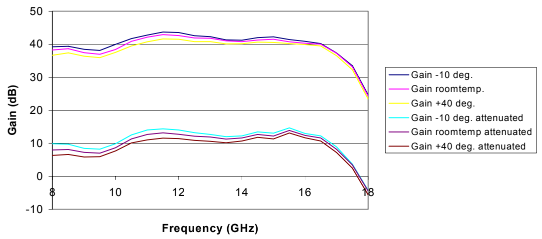

Figure 7: Measured gain with and without attenuation (in temperature) for MUSIC.

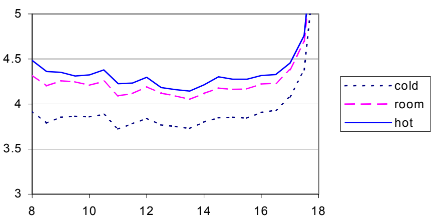

Figure 8: Measured noise (in temperature) for MUSIC.

The suppression of the LO was 10 dB which corresponds with a measured LO suppression of > 20 dB in the mixer, > 4 dB in the IF filter and 16 dB gain in the output amplifier. Target for gain of the non-converted RF leakage signal was <-30 dB below 7 GHz and <-20 dB above 7 GHz. Measured RF suppression was better than 25 dB in the lower frequency band and better than 12 dB in the higher end of the frequency band. It was little or no difference for the results in temperature.

Second run performance

The results for the second iteration, summarized in Table 1, show full functionality and that most of the target specifications were met. There is, however, a gain variation that is larger than target (Figure 9). The main reason was a larger gain variation than simulated for the amplifiers. No temperature measurements were performed for the second iteration.

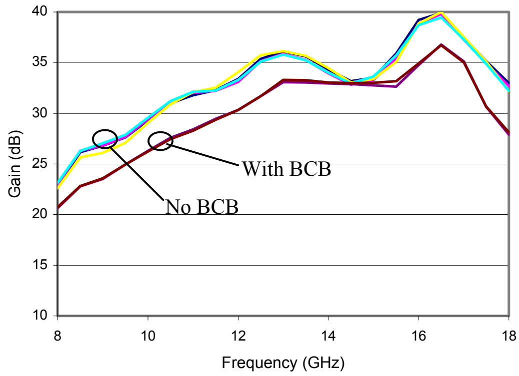

Figure 9: Measured gain for MUSIC second iteration

Parameter	Target	Measured performance	
		0 dB att.	30dB att.
Frequency in [GHz]	2-12	2-12	2-12
Frequency out [GHz]	18-8	18-8	18-8
Noise figure [dB]	< 6	4,4-5,7	-
Gain [dB]	33 ± 4	23-40	-6-9,5
Gain control [dB]	30 ± 2	30±0.5	
P_{1dB} (input, dBm)	>-38 or -8	> -34	> -6,5

Table 1: Results for MUSIC second iteration.

The circuits from the wafer coated with BCB had a gain approximately 2 dB lower and a noise figure approximately 1 dB higher than for the non-coated circuits (Figure 9 and Table 1). The chip was not specifically designed with regard to the BCB-coating and thus a minor loss in performance was to be expected. Measurements performed on test circuits showed small differences with and without BCB for all sub-circuits.

CONCLUSIONS

An ultra broadband upconverter MMIC has been designed and measured in two iterations. The measured results for both design iterations are overall satisfactory with full functionality. It has been shown that complex functionality can be integrated on very compact MMIC's. The target specification was not completely met. For the first run this was mainly due to problems with reaching the full bandwidth in the mixer. In the attempt to solve the problem a new RF-balun with 140 % 1dB bandwidth was designed. New functionality was also introduced in the second iteration in order to reduce the complexity of the chip-interface to allow for simpler integration into a package. Unfortunately the changes to the amplifiers also led to a large gain variation. The difficulties encountered during the design work gave evidence for the need for Momentum simulations of critical parts, especially when designing very complex and highly integrated MMIC's.

REFERENCES

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