High linearity MMIC amplifiers for on-board satellite S-DMB converters

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***Abstract*—This paper presents the design, simulation and measurement of two GaAs P-HEMT high linearity amplifiers for S-DMB applications, operating in the S and UHF bands. The amplifiers are part of a high linearity downconverter, so a specific topology and an active matching network have been chosen to achieve a high OIP3 value as well as good input and output return losses without using any external components. The S-band and UHF-band amplifiers exhibit an OIP3 of 23 dBm and 27 dBm respectively. They have also been measured included in a down-converter, achieving a total gain of 19 dB, an ouput P1dB of 10.5 dBm and a OIP3 of 31 dBm.**

Keywords- Amplifier, GaAs, linearity, MMIC, satellite communications, S-DMB.

I. INTRODUCTION

The introduction of multimedia services in mobile systems is of key importance for mobile operators to maintain their high revenues in the coming years, as other type of services are coming less profitable. Mobile broadcast/multicast technologies are one of the best ways to deliver this kind of services, since the one-to-many distribution mode is the most efficient way in terms of radio/network resources usage and cost to deliver data to a large audience.

S-DMB (Satellite Digital Multimedia Broadcasting) provides a delivery capacity for several mobile operators to provide cost effective streaming and data download services directly in mobile handsets [1]. The system relies on a hybrid satellite and terrestrial repeaters infrastructure, operating in the IMT2000 core frequency band allocated to Mobile Satellite Systems.

This paper presents the design and measurement of two high linearity amplifiers, part of the down-converter in the on-board satellite repeaters. High linearity amplifiers are very important in satellite communications systems, where multi-carriers signals are modulated with variable shape and have to be amplified simultaneously. In order to achieve the required linearity criterion at the output of the receivers, passive mixers (i.e. diode based or cold FET) are commonly used. Since this kind of mixers does not provide gain, it is necessary to include buffer amplifiers to meet the gain requirements of the receiver and at the same time preserve the linearity high.

The MMIC (Microwave Monolithic Integrated Circuit) technology has been used since it reduces cost and weight by two times compared with hybrid technology, which is crucial in satellite communications. The ED02AH process from OMMIC based on GaAs P-HEMT transistors has been chosen. This technology is expensive and power hungry, but it provides high reliability and space qualification, two characteristics that are not common in low cost processes (i.e. SiGe or CMOS) [2].

The design of high linearity amplifiers is not an easy task, as several important specifications need to be met at the same time: input and output matching, linearity and gain [3]. This paper describes the whole process, since the choice of the topology to the measurements, first of the independent amplifiers, and then of the amplifiers integrated in the down-converter. The results show a good agreement between simulation and measurements.

II. DESIGN OF THE S/UHF BAND AMPLIFIERS

The amplifiers have been designed using the ED02AH process from OMMIC, offering P-HEMT transistors with a gate width of 0.2 µm and a transition frequency ft= 63 GHz. The main specifications of the amplifiers, which derives from the general specifications of the complete down-converter are shown in Table I, and are the same for both frequency bands.

The first design attempts aimed at designing a single amplifier for both bands, S-band (between 2 and 2.2 GHz) and UHF-band (between 550 and 750 MHz), allowing the reuse of the same chip. This implied obtaining high linearity in a wide band which covers frequencies from 550 MHz to 2.2 GHz, preserving an excellent input match. The only solution was to include an external matching network at the input fitted for either UHF or S band. In each case we obtain good input match and high linearity, but at the expense of the integration.

To obtain an integrated solution, a different approach was used. As it is indicated in Table I, the amplifiers should present good input and output return losses as well as a high third-order output intermodulation point (OIP3), so the circuits have been split into two stages. The first one is an active input matching stage [4]-[5], formed by a common-gate transistor that reduces

TABLE I. AMPLIFIER SPECIFICATIONS

	Units	Value
Gain	dB	15
Input return losses	dB	-18
Output return losses	dB	-15
OIP3	dBm	25

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the high input impedance of the p-HEMT amplifier, providing an easier input matching. The second stage is composed by a transistor in a common source configuration with parallel feedback in order to improve the stabilization of the circuit. The size of the transistor is chosen to be high, so as to obtain a good linearity value.

Besides the common-gate transistor, an input and output matching network formed by lumped-elements has been included to achieve the return losses specification.

This is the basic topology that is the same for both amplifiers. Nevertheless, there are some differences between them; the input and output lumped matching networks are different since they need to be adapted to the corresponding frequency band. The configuration of the S-band amplifier is shown in Fig. 1. The topology of the UHF-band amplifier is very similar so it is not shown.

A. Active input matching.

The core component of the stage that performs the active input matching is a transistor in common-gate configuration. The input resistance of the transistor is determined by its transconductance value, which is also proportional to the transistor width.

$$Z_{in} = \frac{r_{ds} + R_L}{g_m \cdot r_{ds} + 1} \qquad (1)$$

If we supposed $r_{ds} >> R_L$, which is a good approximation, then the input impedance of the common-gate stage can be approximated by Eq. 2.

$$Z_{in} \cong \frac{1}{g_m} \qquad (2)$$

Where g_m depends on the transistor size and biasing current. The next step to achieve the matching is to verify Eq. 3.

$$Z_{in} \cong \frac{1}{g_m} \cong \frac{\partial V_{GS}}{\partial I_D} \cong 50\,\Omega \qquad (3)$$

When the input stage transistor meet these conditions, a good wideband matching is obtained, but at the same time, the value of the linearity is severely degraded since the corresponding biasing point does not agree with the maximum linearity point obtaining a low IP3 value.

The best solution to this problem consists of changing the biasing point of the input stage to obtain a good linearity and an adequate matching, slightly worst than before. Then, we improve the input matching with a basic on-chip lumped element passive network that otherwise would have been composed by too many elements.

B. Load circuit.

The load circuit of the common source transistor in both designs is formed by a transistor acting as an active load [6] instead other common elements as a resistor or an inductor. The active load presents several advantages against passive

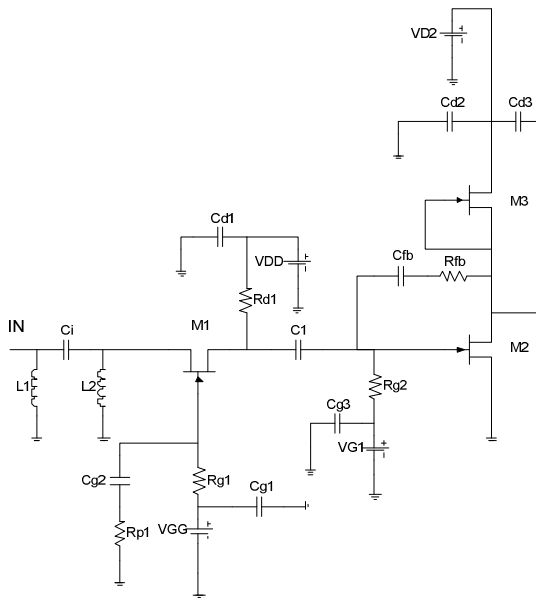

Figure 1. S-band amplifier topology.

components; is a better RF choke allowing a higher linearity of the amplifier, it presents wide band characteristics and it is less area consuming. Moreover, active loads allow higher voltage gain with less DC power.

In this case, where the bandwidth is wide and the operation frequencies low, especially in the UHF amplifier, the inductor would have occupied around 20 times more area than the active load.

III. MEASUREMENT PROCESS AND RESULTS

Two different sets of measurements were performed; first, the two amplifiers have been tested independently in order to check the similarities between simulation and measurement. After this, the amplifiers were included within the mixer to verify the overall behavior of the down-converter.

Fig. 2 presents the chip that contains both amplifiers, as well as a low noise amplifier of the same project. The area occupied by the two high IP3 amplifiers is quite small, being 2.84 x 1 mm including the RF and DC bonding pads.

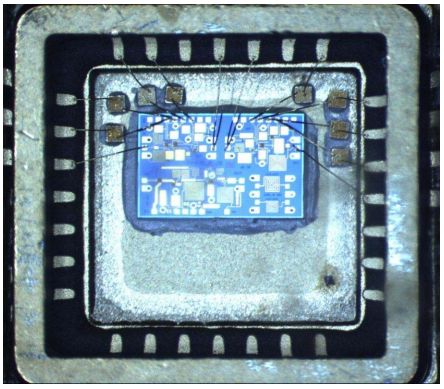

Figure 2. Microphotograph of the packaged amplifiers.

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The S-band amplifier was mounted on a 28 pin package including 100 pF DiCap capacitors in each bias line to avoid low frequency oscillations.

A. Measurement of the amplifiers.

When measuring the circuit with the spectrum analyzer, an oscillation that wasn't detected in simulation by the parameters μ and μ', appears at 1 GHz in the S-band amplifier and at 300 MHz in the UHF-band amplifier.

To find this instability also in simulation, we performed a more accurate stability method based on admittances. This analysis is carried out connecting a small signal current source with a frequency "w" in parallel with the sensitive circuit nodes, which in the case of an amplifier are the transistor terminals (gate, drain and source). The relationship between the current and the node voltage provides the total input admittance from that node. Then, an AC or harmonic balance analysis is carried out and the real and imaginary part of the frequency is represented. From these graphs, it can be observed if the start-up oscillation conditions are fulfilled or not.

The new stability analysis [7] indicates that the amplifier oscillates at the frequencies observed during the measurement. In order to eliminate the oscillation, a new PCB including external stabilization networks was performed.

The comparison between the simulation and measurement results of the S-parameter simulation for the S-band amplifier is shown in Fig.3, and as can be seen, the results are very similar. A voltage gain of 15.3 dB is obtained as well as good input and output matching values. Nevertheless, the frequency shift in the input matching measurement, lead to a degradation of the parameter being the specification barely met. The current consumption of the amplifier is 33 mA over a supply of 3.5 V.

The result in measurements for f=2 GHz is a little lower than in the simulations with a value of -7 dBm of 1 dB compression point at the input while the value obtained in measurements is -4 dBm. Regarding the output 1dB compression points, the values that have been obtained are of 11.8 dBm in simulation and 8 dBm in measurements.

Two-tone measurements have been performed to obtain the third order intermodulation distortion point of the amplifier. Two tones separated 200 KHz and with a power of -25 dBm have been used for the measurements. The measured OIP3 presents a value of 23 dBm, 2 dB below the specifications due to the lower drain current of the amplifier compared to the simulation results. The change in the drain current is due to a variation of the Idss current of the transistor occurred during the fabrication process in the foundry. The third order intermodulation measurement is shown in Fig.4.

The same types of analysis were carried out to the UHF-band amplifier. A gain of 14.8 dB is obtained in measurement while in simulation the value was a little higher, 17.8 dB. On the other hand, the output matching remains below -19 dB in the working frequency band, meeting the given specifications.

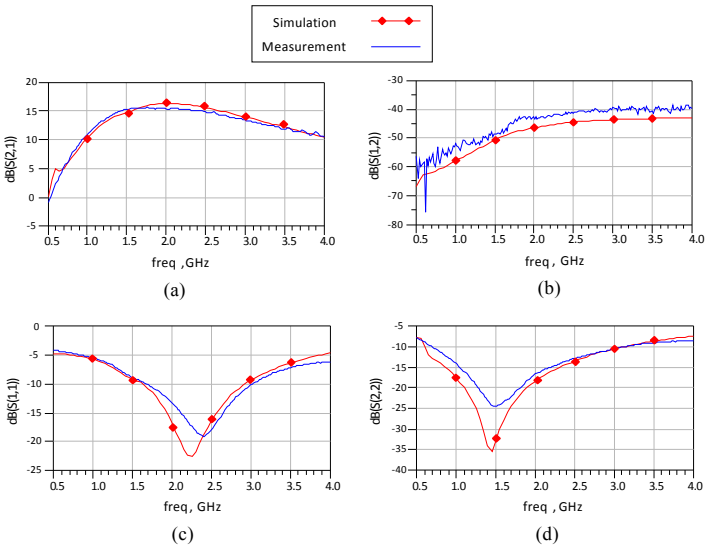

Figure 3. Measurement and simulation result comparison of the S-band amplifier.

The input power was swept in order to obtain the input and output 1dB compression point of the amplifier. The input compression point for f=550 MHz in measurement is the same than in simulation, with a value of -4 dBm. Regarding the output 1 dB compression point, the value in measurement is 11.2 dBm while in simulation was slightly higher, 12.7 dBm.

For the intermodulation measurements, two tones with a separation of 200 KHz were used. Due to the low input power at which the measurement had to be performed (-43 dBm), a highly linear amplifier from Microwave Amps Ltd. Model AL19-1.1-1.7-30 with a gain of 30 dB was used at the output.

For an input power of -43 dBm (the input power set in the specifications), a value of 27.4 dBm at 550 MHz is obtained, while at 750 MHz, the value is 28.2 dBm. Both values meet the specifications.

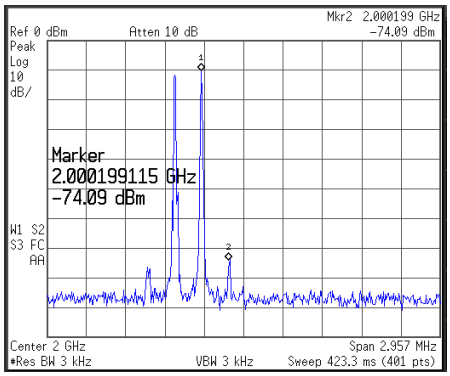

Figure 4. Screen shot of the spectrum analyzer during the intermodulation measurement of the S-band amplifier.

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B. *Measurement of the downconverter.*

Both amplifiers have been tested working together as they will do in the down-converter. The S-band amplifier is placed before the mixer, followed by a low pass filter that filters all the undesired signals out of the band of interest. The intermediate frequency is then amplified by the UHF band amplifier.

A low pass filter with seven sections has been designed using SMD components. The filter must reject the spurious signals as well as the coupled signals from the RF and LO inputs. The losses of the filter are low, about -1 dB in the pass band, and the rejection is high, with a value of -40 dB at 1.2 GHz.

A high IP3 commercial mixer was chosen to perform the test. It is the component SYM-25DHW+ from Mini-circuits, which presents conversion losses of 6.4 dB and an IP3 of 30 dBm.

A photograph, as well as a schematic diagram of the measurement setup in the laboratory is presented in Figure 5 and Figure 6, respectively. The measurements have been performed for two intermediate frequencies, 750 MHz and 550 MHz. The results will be shown only for the IF of 750 MHz, as they are very similar to those of the IF=550 MHz.

For an input power of -40 dBm, the gain of the receiver is 18.6 dB in measurement and 18.8 dB in simulation, values which are very similar. The 1 dB compression point in

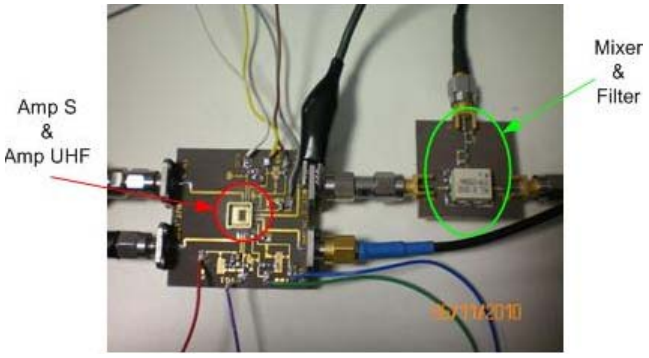

Figure 5. Photograph of the measurement setup.

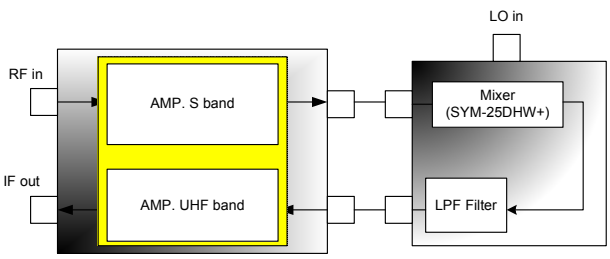

Figure 6. Schematic diagram of the measurement setup.

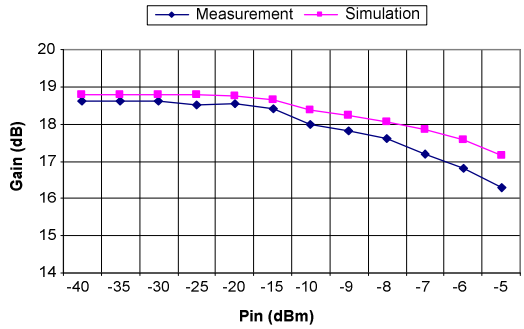

Figure 7. Variation of the gain with the input power in the downconverter.

measurement is -8 dBm. The variation of the gain with the input power is shown in Fig. 7.

The third order intermodulation point has been measured obtaining a value of 31.1 dBm which guarantee a high linearity of the complete downconverter.

IV. Conclusions

Two high IP3 amplifiers in the S and UHF bands for S-DMB applications have been designed using the GaAs ED02AH process from OMMIC. Both amplifiers are completely integrated and its topology has been chosen to present a high linearity, obtaining an OIP3 of 23 dBm in S-band and 27 dBm in UHF band. The amplifiers have been also measured working within a complete down-converter, obtaining again good values of matching and a high linearity.

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