Design of a two-stage MMIC power amplifier at 30GHz for LMDS

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Abstract — **There is a growing need for high data-rate communication, which necessitates applications operating at higher frequencies, scratching over a broader bandwidth. We are going to present here a 2-stage power amplifier (PA), suitable for LMDS applications, according to the IEEE802.16c standard, for which a systematic approach is assisted.**

The power amplifier is designed in the Ommic DH01P 0.13µm PHEMT process technology, which has a transient frequency of 90GHz and a breakdown voltage at 12V.

Based on the systematic approach, the design is separated in two main parts, namely the nonlinear part (load-pull) and a linear part (matching). The output stage consists of 6 PHEMT transistors with each 7 gate-fingers of 10µm. The input stage consists of 2 PHEMT transistors with 7 gate fingers of 10µm. Coplanar waveguide technology is used to realize the matching and biasing circuits to keep the insertion losses low.

The simulated results indicate an overall transducer power gain of 18dB and a single tone output power level of 23dBm. The power amplifier reaches an EVM of 1.5% at an output power level of 17dBm. The achieved efficiency remains around 10% due to the required back-off operation.

Investigation is done to improve simultaneously the linearity and efficiency performance with pseudo input mismatch and IF-termination.

Keywords— **IF-termination; ka-band; linearity; microwave; MMIC; power amplifier; systematic approach.**

I. INTRODUCTION

LMDS stands for Local Multipoint Distribution Service, which is a high data-rate application according to the IEEE802.16 standard. LMDS is a wireless first-mile-last-mile solution for voice, video, data and Internet applications.

The presented power amplifier, designed according to the IEEE802.16 standard, for LMDS applications operates at 30GHz where a lot of parasitics occur. LMDS uses a 64-QAM signal, which has a peak-to-average ratio (Crest-factor), which is an important design constraint. In this case not only 1dB compression in the AM-to-AM characteristic is important, but also the impact of AM-to-PM is critical. The main trade-off is linearity versus efficiency, due to the complex modulated signal (64-QAM). Input-power back-off is needed.

Simultaneously improvement of linearity and efficiency is investigated through different methods e.g. pseudo input mismatch [3] and IF-termination [1], [4].

Ommic DH01P 0.13µm PHEMT process technology is used to design the power amplifier, which has a transient frequency of 90GHz and a breakdown voltage at 12V.

A systematic designed, simulated linear two-stage power amplifier, suitable for LMDS applications is presented here.

II. SYSTEMATIC DESIGN APPROACH

A systematic design procedure, based on a top-down approach is employed to design the power amplifier. The system is separated in two main parts, namely the non-linear part (load-pull) and a linear part (matching). So the system is separated in different "semi-independent" building blocks to reduce the complexity per design step.

First the output-stage is designed, followed by the input-stage and matching and biasing networks, started with the output matching, followed by the interstage matching and the input matching [1].

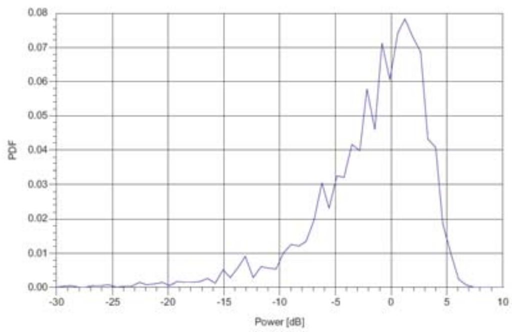
The output-stage is designed to provide the specified output power, best possible efficiency and the specified linearity requirements. The output-stage consists of 6 PHEMT transistors, with each a total gate length of 70µm.

The input-stage is designed to achieve maximum power gain and to provide the needed output power to let operate the output-stage optimal. The input-stage consists of 2 PHEMT transistors with each a total gate-length of 70µm.

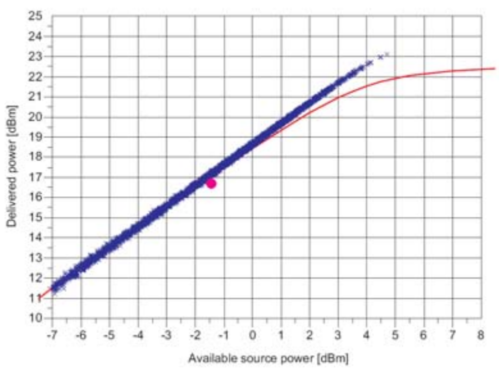
Matching and biasing networks are designed with coplanar waveguide (CPW) technology to keep the insertion losses as low as possible. The matching networks consist of combinations of CPWs and capacitors to keep the circuits simple.

III. IMPACT OF AM-TO-PM CHARACTERSTIC ON THE TWO-STAGE DESIGN PROCEDURE

Figure 1 presents the probability density function of the power distribution of the used 64-QAM modulator. The peak-to average ratio is around 7dB, which is important for the linearity of the system. Also the power distribution is shown on the AM-to-AM characteristic (1b) to show the impact on the linearity.



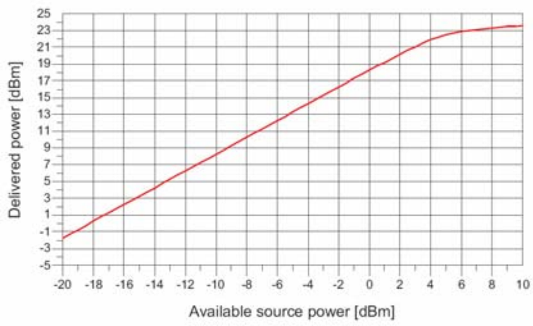
(a)



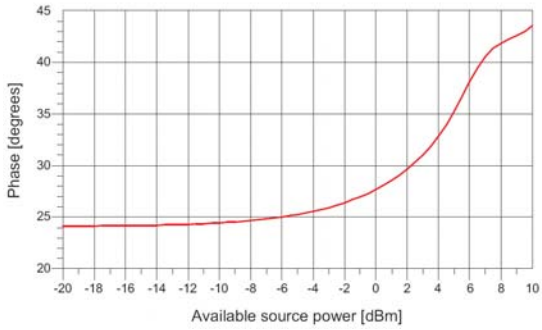
(b)

Figure 1. (a) Probability density function of the power distribution of a 64-QAM signal. (b) 64-QAM power distribution on the AM-to-AM curve,

In figure 2 can be seen that the AM-to-PM non-linearity starts at already -10dBm, while the AM-to-AM non-linearity starts at 6dBm. So when taken into account the peak-to-average ratio of the 64-QAM signal, the AM-to-PM distortion is the dominant non-linearity, because it gets earlier non-linear.



(a)



(b)

Figure 1. (a) AM-to-AM characteristic of the input-stage (b) AM-to-PM characteristic of the input-stage.

IV. INPUT-STAGE LINEARITY

To improve the linearity of the input-stage, the input-stage transistor is scaled twice as big as when scaled on the 1dB compression point in the AM-to-AM characteristic, because the AM-to-PM characteristic is dominant

Also linearity improvement by pseudo input mismatch [3] is employed to get a better linearity performance at the input-stage.

When the input power changes, the input impedance changes (see figure 3a). These different input impedances are all well matched, but on different power levels. The principle of pseudo input mismatch is to match the input impedance on the 1dB compression point, determined after a conjugate match on low power with s-parameter simulation.

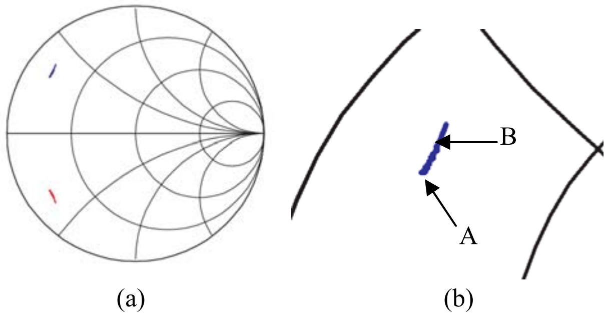


Figure 3. (a) Input impedances and the complex conjugated impedances when input power is swept. (b) Zoomed part of the Smith-chart, where A is low power and B is around 1dB compression.

Normally the input is matched at point A (linear operating area) in figure 3b, which results in a gain curve like curve A in figure 4.

The result of pseudo input mismatch, when matched at point B (around 1dB compression point) in figure 3b gives curve B in figure 4, which result is an input mismatch at the lower power gain area and a gain expansion near to the 1dB compression point of the input-stage. So an improved 1dB compression point is got.

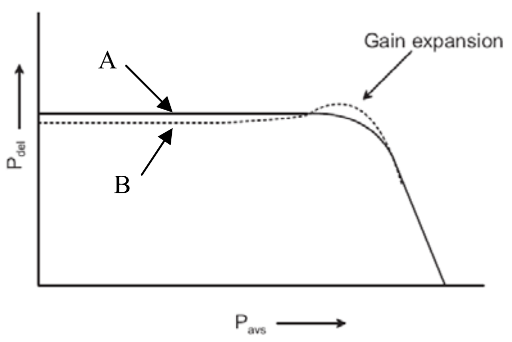


Figure 4. Gain expansion by pseudo input mismatch.

V. LINEARITY IMPROVEMENT BY IF-TERMINATION

An investigation is done to improve simultaneously the linearity and efficiency performance by IF-termination to improve the performance of the designed power amplifier.

Important for linearity are the third order intermodulation products (IM3), which consist of direct mixing products ($2\omega_1 - \omega_2$) and ($2\omega_2 - \omega_1$). And consist also of indirect mixing products ([2], [4]), as a result of mixing of the fundamental tones with the baseband second order intermodulation product ($\omega_2 - \omega_1$) and the second harmonic ($2\omega_1$ and $2\omega_2$).

$$y(t) = a_1 x(t) + a_2 x(t)^2 + a_3 x(t)^3$$

The principle of IF-termination is to achieve a dedicated impedance at baseband frequency, which affects the second order intermodulation product (IM2) ([1], [4]) as presented in figure 5. This impedance has to change the contribution of IM2 to IM3 to get a positive effect on the third order intermodulation products at the high frequency.

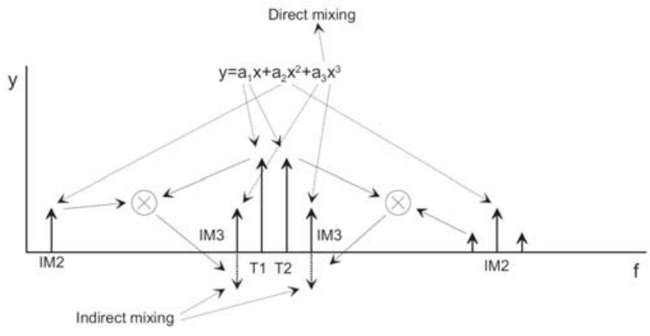


Figure 5. Mixing products of a two-tone simulation [2].

Investigation is done for the effect of IF-termination, when using a complex modulated signal, like 64-QAM in LMDS. Also in this case critical is besides AM-to-AM also AM-to-PM distortion, which is the dominant non-linear distortion in this design.

Figure 6 shows a part of the load-pull simulation setup, where besides a RF load-tuner also an IF load-tuner is used to sweep the reflection coefficients at the IF frequencies.

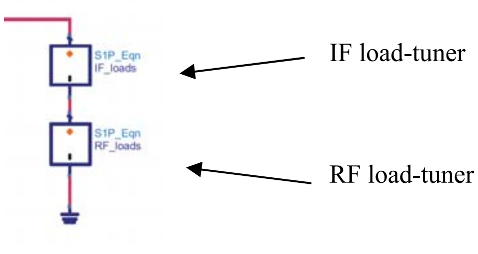


Figure 6. Additional IF load-tuner to carry out the load-pull algorithm on the IF frequency.

VI. SIMULATION RESULTS

The simulation results, according to ADS 2003c indicate a linear power amplifier, which meets the linearity and output power specifications of the IEEE802.16c standard. This is simulated with a 64-QAM modulator as source.

Figure 7 presents the single tone AM-to-AM characteristic of the 2-stage power amplifier. 18dB gain is achieved and the 1dB compression point is at 23dBm output power, which is necessary due to the peak-to-average ratio of the 64-QAM signal, which is 7dB.

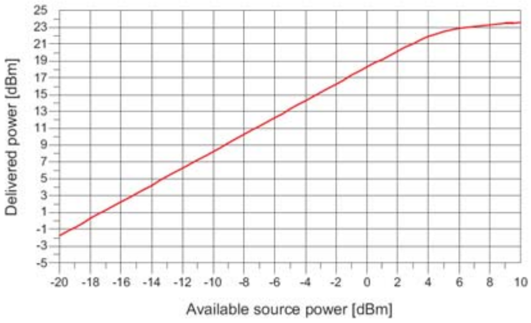


Figure 7. AM-to-AM characteristic of the complete power amplifier.

Due to the peak-to-average ratio of the 64-QAM signal input power back-off is needed to achieve the specified error vector magnitude, according to the IEEE802.16c standard. From simulation results in figure 8 can be extracted that 6.5dB back-off is needed to achieve the required 1.5% EVM. The needed back-off is determined with the 1dB compression point of the 1-tone AM-to-AM curve.

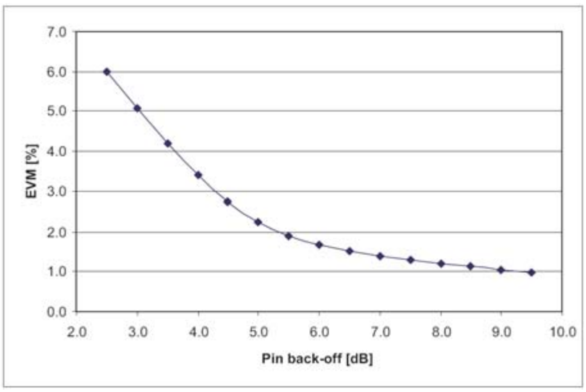


Figure 8. Error vector magnitude in percentage versus input-power back-off.

The spectrum mask, according to the European Telecommunications Standards Institute (ETSI) and the output spectrum of the power amplifier are presented in figure 9.

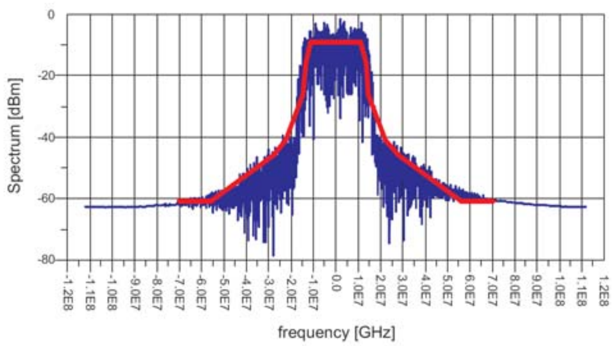


Figure 9. The output spectrum and the spectrum mask according to ETSI.

IF-termination is investigated with ideal circuit components, like DC-blocks and DC-feeds. First a reference circuit with the used output-stage transistors is designed. Followed by a circuit with additional IF load-tuners to employ a load-pull simulation on the IF frequency.

The best result in change of the 1dB compression point is got when the IF impedance is open circuit as well at the input as at the output of the transistor.

Figure 10 presents the AM-to-AM characteristic of the ideal or reference circuit and the circuit with IF termination with a two tone simulation.

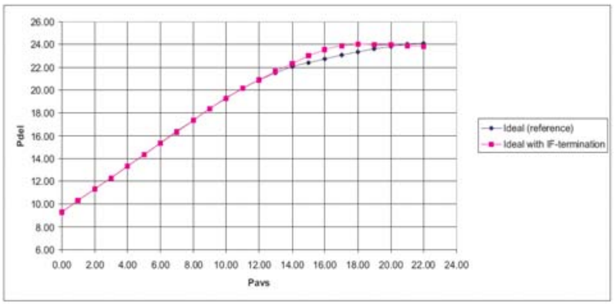


Figure 10. AM-to-AM curve of the reference circuit and circuit with IF-termination.

The AM-to-PM characteristics of both circuits are presented in figure 11. The characteristics of both circuits are the same. No impact on AM-to-PM is observed in this case.

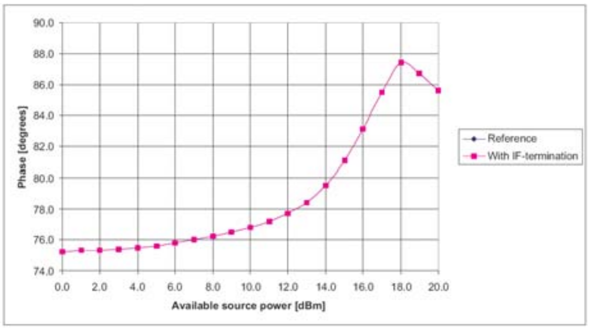


Figure 11. The AM-to-PM curve of the reference circuit and circuit with IF-termination.

The effect of the improvement of the 1dB compression point in the AM-to-AM curve is verified with the 64-QAM modulator and is presented in the table below. Here the reflection coefficients are shown on IF and RF frequencies, with the changes in EVM.

IF source [Γ]	RF source [Γ]	IF load [Γ]	RF load [Γ]	P_{del} [dBm]	EVM [%]
-1	-1	-1	-1	18.7	1.6
-1	-0.99	-1	-0.99	18.4	1.4
1	-1	1	-1	18.7	1.6
Γ_{source}	-1	Γ_{load}	-1	18.7	1.6

Notable is the sensitivity of the system when the IF load-tuners give no ideal shortcut at the RF frequencies. Further no impact is observed when employing IF termination with a 64-QAM signal.

VII. CONCLUSIONS

A simulated linear two-stage MMIC power amplifier is presented, which is suitable for complex modulated signals, like 64-QAM in LMDS.

A systematic design approach is employed to design the presented power amplifier.

AM-to-PM distortion is the dominant factor for non-linearity of this system, because AM-to-PM non-linearity starts earlier than the AM-to-AM non-linearity.

Linearity improvement by pseudo input mismatch is employed to improve the linearity of the input-stage.

Linearity improvement by IF termination is investigated when using a complex modulated signal, like 64-QAM which resulted in an improvement of AM-to-AM distortion. However, in our case we couldn't succeed to observe an improvement in the AM-to-PM characteristic or EVM. Verification with other transistor models and simultaneously with real transistors can give a more clear result.

VIII. REFERENCES

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