Compensation of MMIC Spread in 60 GHz Telecommunication Module by Automatic Output Power Control

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***Abstract* — Cost effective measures for compensation of component spread are required in mass production of mm-wave telecommunication modules. We present the development and implementation of an automatic output power control in a 60 GHz transceiver module in production at the MicroWave Factory of EADS. Without using any additional MMIC module production yield is increased significantly.**

I. INTRODUCTION

mm-wave telecommunication modules based on GaAs MMICs are manufactured in automated assembly lines in the course of which typical production numbers today are several thousand modules per year. As module price is a key success factor achievement of overall high production yield is necessary. Factors affecting yield are e.g. production technology, chip design and biasing [1].

The major contribution to module spread is due to spread in MMIC performance. Both individual tuning of modules and selection of optimum chip sets are no cost effective measures for compensation of chip spread. We therefore think that in complex mm-wave modules designed for mass production the implementation of an automatic gain or power control is inevitable to compensate MMIC spread.

Up to frequencies of about 50 GHz the design and realization of such control loops is state of the art as VGAs or variable attenuators which are key building blocks for a power control loop are commercially available. In the 60 GHz frequency band, which is used for communication applications worldwide, no COTS products providing variable gain or attenuation in chip form are available.

In this paper we present the development and implementation of an automatic output power control into a 60 GHz telecommunication module in production at EADS.

II. SYSTEM OVERVIEW

The automatic output power control developed at EADS was designed for implementation into a specific module but the approach can be easily generalized and applied to a whole family of module designs having the characteristics described in the following.

Figure 1 shows a principle block diagram of a transceiver module operating in TDD (time division duplex) mode. Transmit and receive path are separated using two SPDT (single pole double throw) switches. In receive (RX) mode the LO signal and the receive signal are switched to the mixer. In transmit (TX) mode the oscillator signal is switched via the TX path to the antenna.

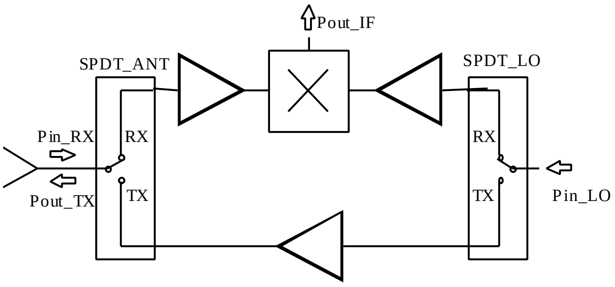

Fig. 1. Block diagram of transceiver module

The LO signal is typically generated by a chain of MMICs consisting of a VCO, multipliers and amplifiers. If MMICs in this chain are operated in linear mode only, MMIC temperature variation (0.014dB/K per amplifier stage) and production spread cause a variation in the LO signal power level Pin_LO of several dB already. At the same time specified module performance must be guaranteed. Overall module specifications are strongly influenced by FCC and/or ETSI regulations. In case of TX output power these regulations and the demands of the net suppliers result in a limited window specified for TX output power. In our application, it turned out that hitting a specified output power window of ± 3 dB within a temperature range of –40 to +80 °C is one of the hardest specifications to meet in production. High production yield can only be achieved if an output power control loop that keeps output power at a given fixed level is implemented.

Simulations on chip level and measurements on test configurations revealed that in the system configuration described above an automatic output power control loop can be implemented by using one SPDT switch

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(SPDT_ANT) as power detector and the other switch (SPDT_LO) as variable attenuator in TX mode. The control loop is closed by a control electronic circuitry (figure 2).

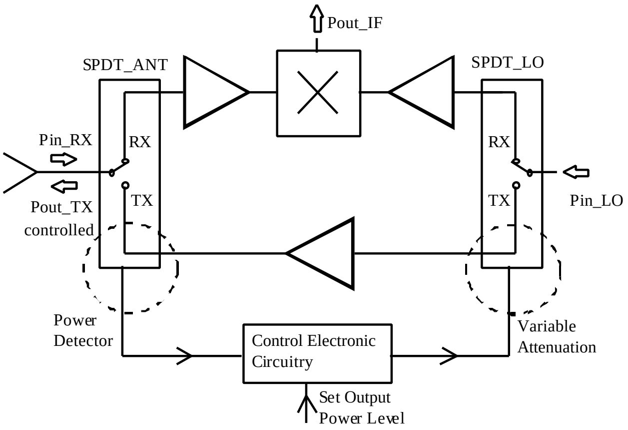

Fig. 2. Block diagram of transceiver module with output power control loop

In the following the behavior of the switch MMIC used in our module is described for SPDT, detector and variable attenuator operation.

II. SWITCH MMIC IN SPDT, DETECTOR AND VARIABLE ATTENUATOR OPERATION

A. *SPDT OPERATION*

The switch MMIC was designed on the Schottky diode technology of United Monolithic Semiconductors (UMS) to be operated as reflective SPDT switch in the frequency range 50-60 GHz. It is commercially available as a catalogue product from UMS. Fig. 3 shows a principle circuit diagram of the switch including off chip resistors needed for constant current biasing in OFF state.

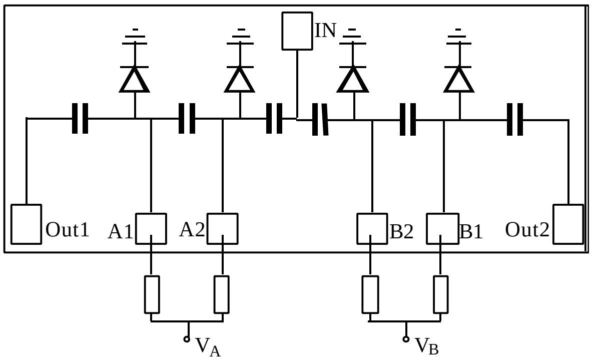

Fig. 3: Principle circuit diagram of SPDT switch

Switching between OUT1 and OUT2 is performed by biasing the diodes in one arm in reverse and in the other arm in forward bias operation or vice versa. The underlying circuit principle is described in detail in [2].

Table 1 contains typical insertion loss and isolation for both switch states.

	State 1	**State 2**
Bias	V_A= -2.5V V_B= 3.3 V ($I_B \cong$24mA)	V_B= -2.5V V_A= 3.3 V ($I_A \cong$24mA)
Insertion Loss IN → OUT1	1.5dB	25dB
Insertion Loss IN → OUT2	25dB	1.5dB

Table 1 Insertion loss and isolation of SPDT MMIC

B. *VARIABLE ATTENUATOR OPERATION*

Simulations on chip level using the LIBRA series IV circuit simulator revealed that switch isolation in OFF state can be continuously adjusted by variation of forward bias voltage. High forward bias current yields high reflection and thus high isolation. Maximum isolation of about 30 dB corresponds to maximum allowed DC current in Schottky diodes (in our application 15mA per diode). This effect allows usage of one switch arm as variable attenuator within the system. Input power is applied to port IN, the switch arm IN→OUT1 is biased in ON state (V_A=-2.5V) and the insertion loss in arm IN→OUT2 is adjusted by variation of bias voltage V_B between 0 and 4V. Figure 4 shows results of on wafer power measurements at 58 GHz in a test configuration where port OUT1 was terminated with a 50Ω load. Insertion loss of the switch was adjusted by variation of control voltage V_B from 0 to maximum 4 V.

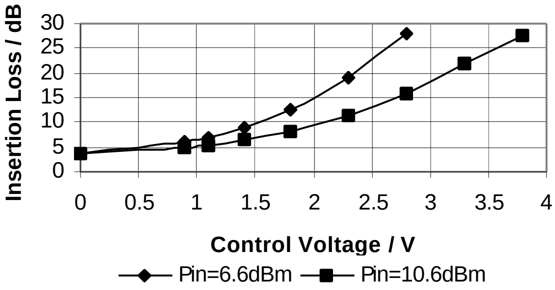

Fig. 4. Insertion loss of variable attenuator (switch arm IN→OUT2)

Insertion loss of the switch arm can be varied from 4 to 25 dB. Absolute value of insertion loss depends on control voltage and input power. The dynamic range of the variable attenuator is 20 dB at input power levels of about 10 dBm.

C. POWER DETECTOR OPERATION

The possibility to use the SPDT_ANT switch as power detector in TX mode was first checked by simulations and then confirmed by on chip power measurements in several test configurations. Power was applied to port OUT1 of the chip and output power was measured at port IN while the arm between IN and OUT2 was switched OFF (V_B=3.3V). Bias voltage V_A was set to zero and rectified voltage was measured at pad A2. In Figure 5 detector voltage measured at pad A2 is depicted as a function of output power measured at port IN. The frequency of the input signal was 58 GHz.

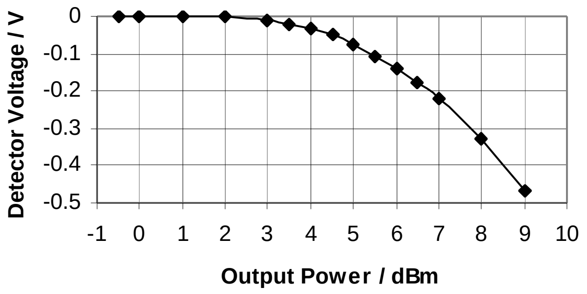

Fig. 5. Detector voltage versus power

The results show that for 3dBm < Pout < 10dBm detector voltages are in a range that can be handled easily by a control electronic circuitry. Also shift of detector voltage versus temperature can be accounted for within the control electronics. Thus it is possible to use the switch as detector in output power control loops where output power should be kept constant at a level of about 5 dBm and higher. Please note that the use of a more sensitive or accurate detector is not required for a system where output power has to be kept constant within a given window of about ±2dB only.

III. IMPLEMENTATION OF TX POWER CONTROL IN 60 GHz TRANSCEIVER MODULE

To implement an automatic power control loop that keeps output power constant at a given fixed level one needs three main building blocks. A power detector that measures the signal to be kept constant, a circuit with which output power can be varied (a variable attenuator or a VGA) and a control electronic circuitry which provides the feedback between control voltage and detected power. A prerequisite for the application of a variable attenuator is of course to have sufficient available gain.

Figure 2 shows how we arranged these functions in a 60 GHz transceiver module. The characteristics of the variable attenuator and power detector we used were already presented in the previous section. The control electronics is an analog circuitry which contains the setting of the absolute power level and furthermore takes care of temperature compensation of detector voltage. Within the module the electronics is realized on a thick film electronics board.

Figure 6 shows measurement results performed with open and closed power control loop in a test module. In case of the open loop, the control voltage at the variable attenuator was set to 0 V which corresponds to minimum insertion loss and thus maximum available power of the module.

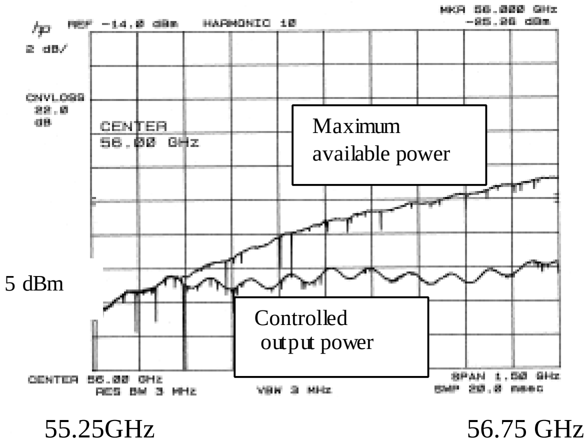

Fig. 6. Difference between open and closed control loop operation.

In the controlled case, output power is kept constant at a power level of 5 dBm. Output power can be kept constant at this level as long as maximum available power in the module is more than 5 dBm. In the depicted example this is not the case for frequencies below 55.5 GHz.

The frequency band of operation of the module now in production at EADS is 57.2 to 58.2 GHz. The specified window for TX output power is ± 3dB. Figures 7 to 9 show measurement results from 70 prototypes with implemented output power control loop measured at -40°C, +25°C and +80°C.

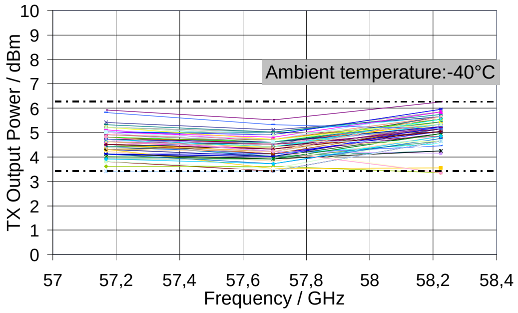

Fig. 7. Controlled output power of 70 prototypes measured at -40 °C.

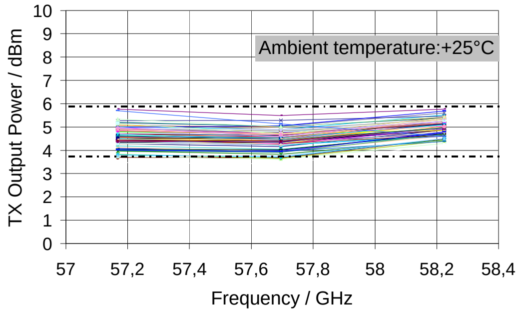

Fig. 8. Controlled output power of 70 prototypes measured at +25 °C.

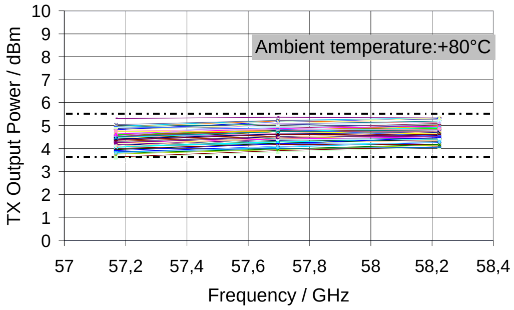

Fig. 9. Controlled output power of 70 prototypes measured at +80 °C.

The measurement data depicted in figures 7 to 9 demonstrate that module output power is successfully stabilized over the whole temperature range from –40 to + 80°C. For all prototypes controlled module output power lies within a window of only ± 1.5dB.

These results show that without using additional chips, we were able to successfully implement an automatic output power control into a 60 GHz transceiver modul in production.

IV CONCLUSION

We presented the development and implementation of an automatic output power control loop into a 60 GHz transceiver module as a cost effective method to compensate chip spread and temperature drift. Without using any additional MMIC or any manual tuning steps mm-wave module production yield is increased significantly.

A patent application for the presented topic is filed.

ACKNOWLEDGEMENT

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