

Electronic calibrator MMIC with frequency range up to 50 GHz for vector network analyzers in GaAs pHEMT technology

Daniil Danilov^{1}, Nikolai Drobotun², Aleksei Medvedev¹, and Vladimir Ulyanov¹*

¹MICRAN, Research and Production Company,

²Tomsk State University of Control Systems and Radioelectronics

Abstract. This paper presents design, simulation and measurements results of electronic calibrator with frequency range up to 50 GHz in GaAs pHEMT technology. MMIC was fabricated by using in-house 0,5 μm pHEMT process. Designed MMIC performs SOLT calibration method with additional measures

1 Introduction

For research, tuning, testing and measurements of RF and microwave parameters in nowadays electronic manufacturing vector network are used. Vector network analyzers (VNA) are designed for the most complete measurements of single-port and multiport devices used in radio electronics, communications, radar, and measuring equipment [1]. For accurate measurements it is necessary to eliminate the measurement error and to minimize measurement uncertainty. The measurement error can be divided into three groups: systematic, random, and drift error. The largest influence is made by the systematic error caused by the non-ideal hardware implementation of the analyzer measuring path. In general, the measurement error is determined by the quality of the calibration. Calibration is a process, as a result of which the systematic error factors are mathematically extracted. Calibration of a vector network analyzer is traditionally performed by using a set of calibration measures (calibration kit). Such calibration is time consuming and takes considerable period. The electronic calibrator is designed for automatic calibration of the VNA. Automatic calibration process offers the advantage of ease of use and high calibration speed with comparable error values.

2 Electronic calibration concept

An electronic calibrator MMIC was developed for a vector network analyzer manufactured by MICRAN company. The chip was designed on the basis of switching pHEMT transistors with gate length of 0,5 μm . As usual transistors with gate length of 0,5 μm are not applicable in the frequency range up to 50 GHz, therefore, to compensate for spurious

* Corresponding author: danilov.ds@micran.ru

parameters (input and output capacities), it is proposed to use segments of transmission lines of a certain length as distributed compensating elements. The main feature of the designed calibrator MMIC is the use of the SOLT family calibration with additional Short and Open loads (from the first letters of the words: SHORT - short-circuited load, OPEN – open-state load, LOAD - matched load, THRU - line between ports, as well as two additional short circuit loads with a line and open state), which allows to increase the calibration accuracy, as well as use this chip as an impedance tuner for measuring noise parameters. Simplified circuit of electronic calibrator is shown in Fig.1.[2]

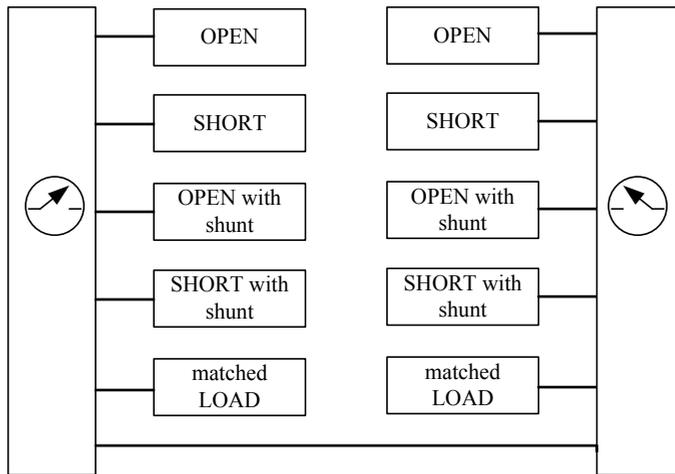


Fig. 1. Structural circuit on the electronic calibration unit.

This calibration unit provides six loads to perform VNA calibration: OPEN, SHORT, OPEN with a shunt, SHORT with a shunt, matched LOAD and a THRU line. Each necessary load is switched on with by using direct current controlled switches. As a switching element, a field effect transistor with a Schottky gate is used. Electrical circuit of electronic calibrator is shown in Fig.2.

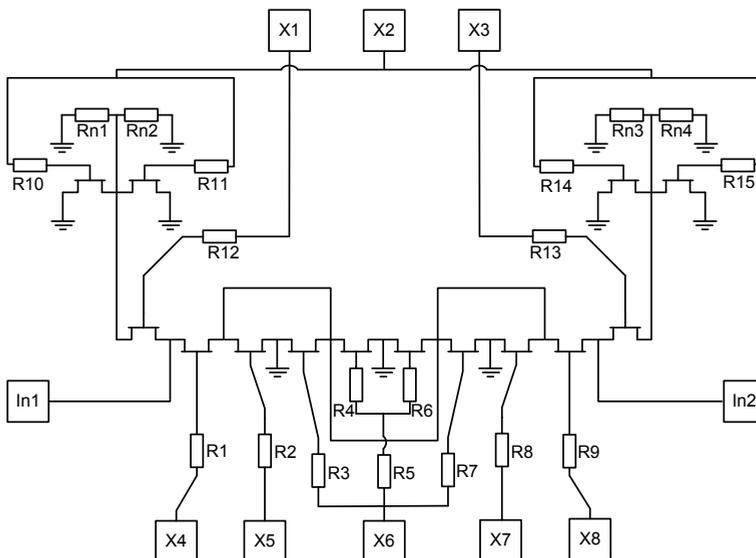


Fig. 2. Electrical circuit of electronic calibrator.

In Fig. 2, the In1, In2 pads are the calibrator inputs. Pads X1 through X8 — Calibrator Load Control pads. Resistors Rn1 to Rn4 are the matched loads of the calibrator. Resistors R1 to R15 are the resistors at the gates of transistors.

During the MMIC design and simulation process, the minimum number of transistors was used to reduce the transmission losses in THRY state and reduce the stray resistance for the coordinated states. The initial characteristics of the electronically switched loads were determined, after which a complete electromagnetic simulation of transistors, calibrator loads and the topology as a whole was carried out.

3 Topology simulation process

The main element that affects the calibrator MMIC performance is a transistor, so at the beginning of the design process, a switching pHEMT transistor with a gate length of 0,5 um was simulated. The main electrical parameters of the switching pHEMT are characterized by the total drain-source resistance with the open channel R_{ON} and the stray total capacitance C_{OFF} (drain-source) in the closed state.

One of the parameters of the switching microwave element which describe its quality is the critical frequency. The critical frequency of the switching pHEMT is defined as:

$$f_{cr} = \frac{1}{2 \cdot \pi \cdot R_{on} \cdot C_{out}} \quad (1)$$

3D model of the transistor for OFF and ON states is shown in fig.3.

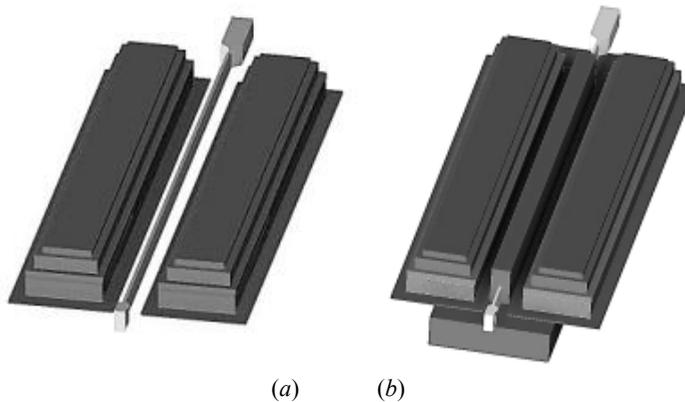


Fig. 3. 3D model of the transistor for OFF (a) and ON (b) states.

Initially the calibrator loads have been developed. During the simulation, was found that due to the transistors' own resistance, the calibrator loads are mismatched, and the MMIC performance in the frequency range from 30 to 50 GHz. Therefore, the simulation of loads was carried out taking into account the influence of transistors and using compensating elements in the form of segments of transmission lines.

Figure 4 show the topology of the calibrator matched LOAD. To reduce the parasitic effect of ground inductance, it was decided to connect two resistors to the ground in parallel with a total resistance of 30 ohms. This value was chosen taking into account the influence of the resistance of the transistors and the matching line, which together with the resistance of the resistors gives a load of 50 Ohms.

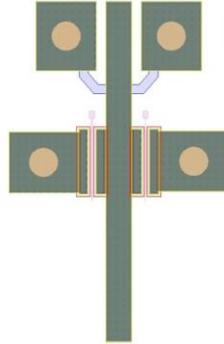


Fig. 4. The topology of matched LOAD.

Simulated vs measured S11 and S22 are shown in fig. 5 and fig. 6.

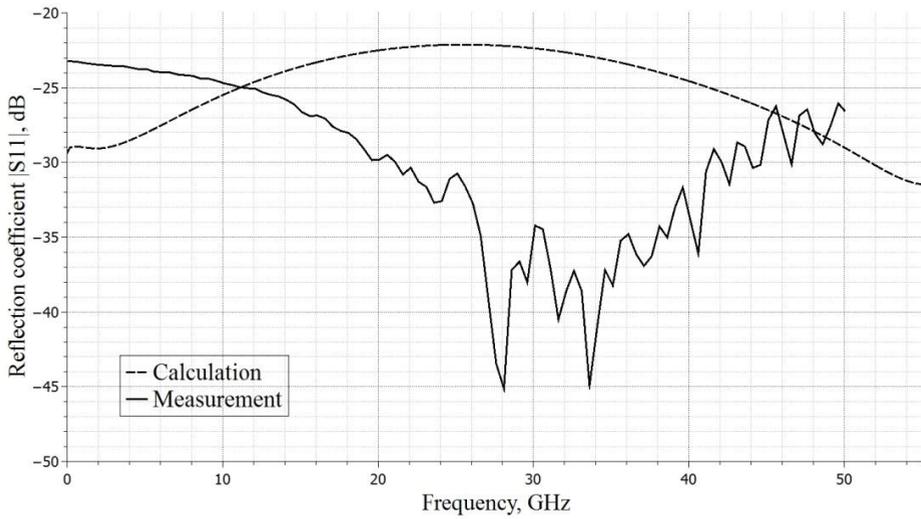


Fig. 5. Simulated vs measured S11.

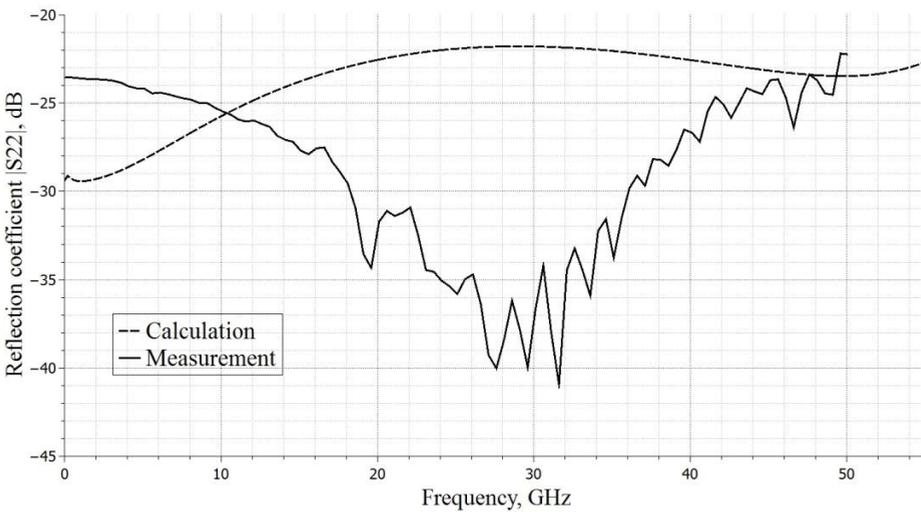


Fig. 6. Simulated vs measured S22.

Afterwards the topology of the THRU line and the OPEN and SHORT loads were developed. Simulations were carried out taking into account the influence of the matched LOAD. Compensating line segments have been selected to reduce THRU line losses and improve port matching.

Full 3D model of MMIC topology is shown in fig. 7.

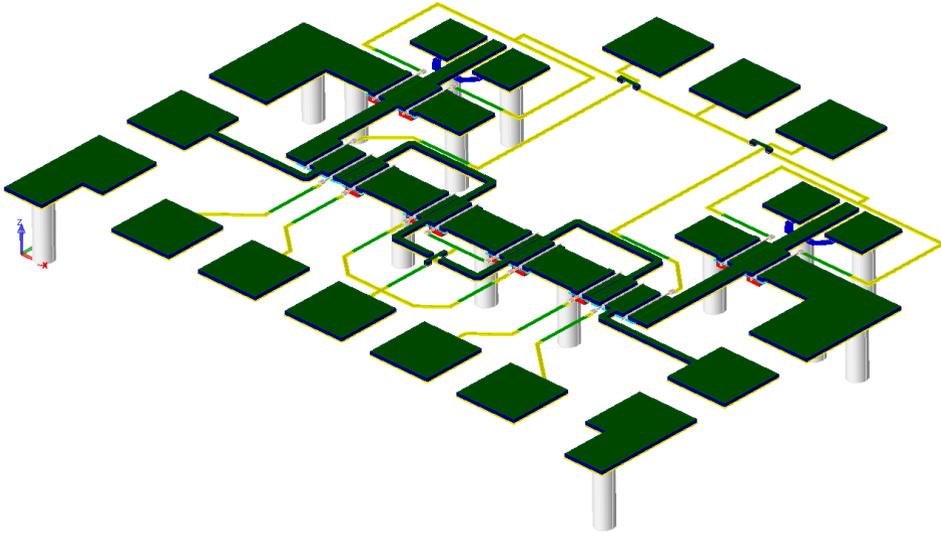


Fig. 7. Full 3D model of MMIC's topology.

Measured vs simulated performance is shown in Fig. 8 and Fig. 9.

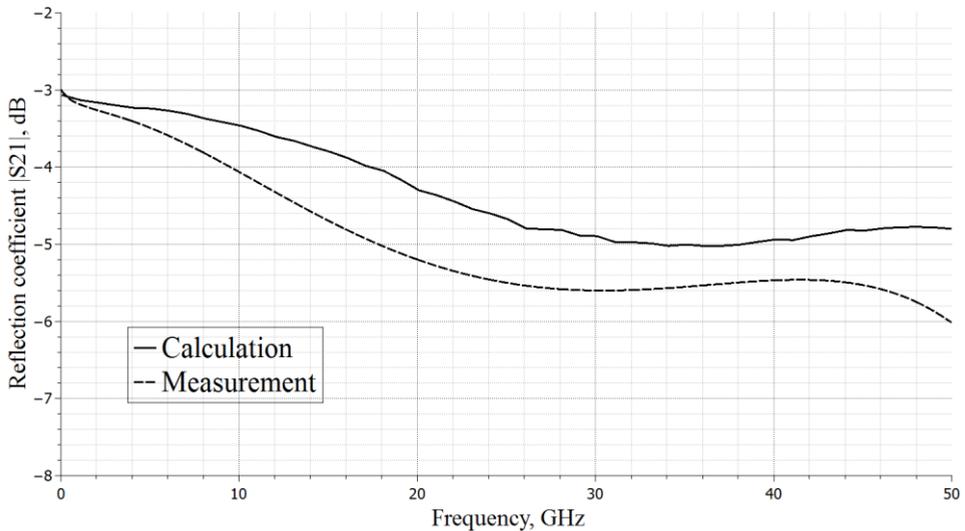


Fig. 8. Measured vs simulated S_{21} (transmission losses, THRU).

For correct and accurate calibration, the difference between the phase of the OPEN and the SHORT should not exceed 120 degrees in the operating frequency range. The required phase shift was provided with the certain line length from the port input to the open transistor to ground (SHORT) and the closed transistor (OPEN). Measured vs simulated phase imbalance for OPEN and SHORT states are shown in Fig. 10.

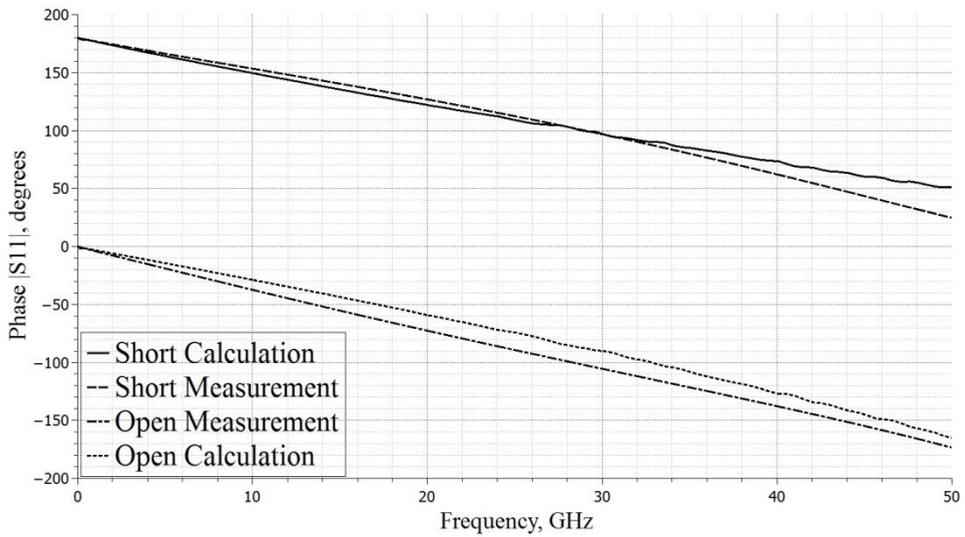


Fig. 9. Measured vs simulated phase balance for OPEN and SHORT states.

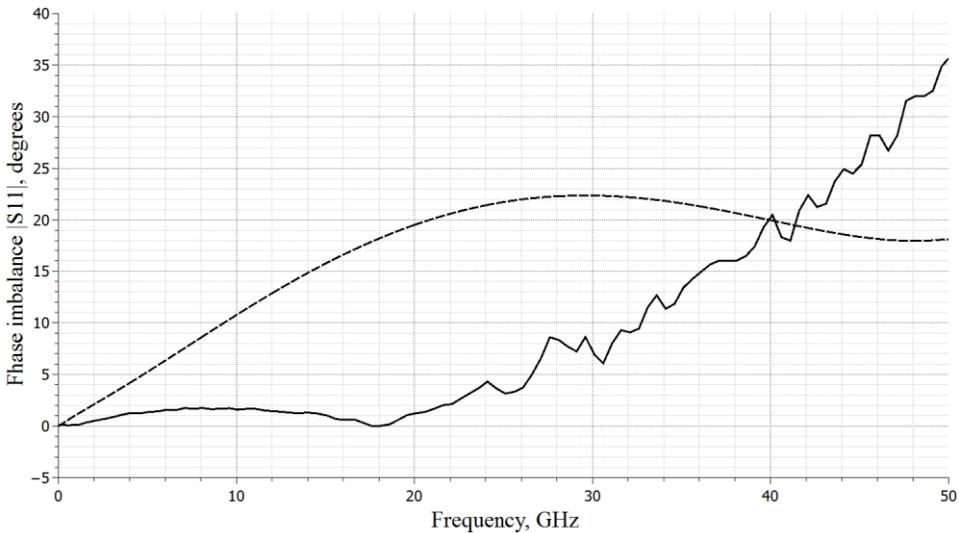


Fig. 10. Measured vs simulated phase imbalance for OPEN and SHORT states.

Figure 10 shows the phase difference between OPEN and SHORT does not exceed 40 degrees, which meets the requirements. The phase difference was tuned by selecting the line length to the cliff (OPEN) and to the ground (SHORT). To ensure the required phase imbalance, the line length for both loads should be equal.

The designed MMIC contains two additional loads; this calibration unit can be used as an impedance tuner to measure noise parameters. In the process of measuring noise parameters, it is necessary to change the impedance of the port connected to the input of the DUT. An electronic calibrator is used as an impedance tuner. To measure the transmission and reflection coefficients (S-parameters), the MICRAN VNA (Panorama series) was used. Connection of the DUT, calibrator and VNA is shown in the Fig. 11 [2].

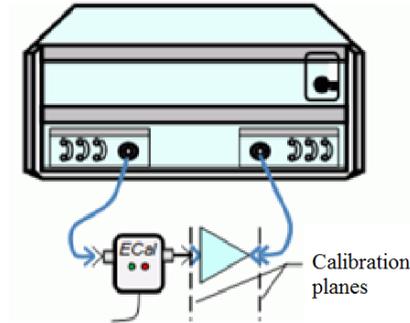


Fig. 11. Noise figure measurements by using MICRAN VNA.

4 Conclusion

The result of this work is fabricated calibration unit MMIC based on pHEMT switching transistors. Calibration using the developed MMIC requires only one connection for a full two-port calibration, which greatly increases the calibration speed. The feature of electronic calibrator MMIC is the feasibility to calibrate vector network analyzer in the frequency range up to 50 GHz. During the simulation, the parasitic parameters of pHEMT and ground inductance were taken into account, what made it possible to obtain level of reflection coefficient lower than -22 dB and minimize THRU line losses. Due to presence of additional loads the designed MMIC can be used as an impedance tuner to measure noise parameters.

The work was financially supported by the Ministry of science and higher education of the Russian Federation on the draft 14.577.21.0279 of 26.09.2013, ID RFMEFI57717X0279. The measurements were conducted at the equipment Center for collective use "Pulse" TUSUR.

References

1. Hiebel M. *Fundamentals of vector network analysis*. (Germany, 2007. URL: <http://www.rohde-schwarz.com>.)
2. Joel P. Dunsmore, *Handbook of microwave component measurements with advanced VNA techniques* (John Wiley & Sons, Ltd., 2014)