A Double Mirror Stub Design of Broadband Planar Bias Tee for System on Chip Integration

Rahul Yadav, Sascha Preu and Andreas Penirschke

May 21, 2022

A Double Mirror Stub Design of Broadband Planar Bias Tee for System on Chip Integration

Rahul Yadav*†, Sascha Preu* and Andreas Penirschke†
*Terahertz Devices and Systems
TU Darmstadt, Darmstadt, Germany
Email: (yadav, preu)@imp.tu-darmstadt.de
†High Frequency Technology
Mittelhessen University of Applied Sciences, Friedberg, Germany
Email: andreas.penirschke@iem.thm.de

***Abstract*—Terahertz (THz) domain is quickly developing with various applications such as beam diagnostics at particle accelerators, spectroscopy, communications, space science, etc. However, often requiring fast intermediate frequency (IF) electronics. We present the design of a double mirror stub (DMS) based a planar broadband bias tee having an isolation port S_{31} with 14.45 GHz bandwidth below -10 dB and S_{33} with 13.1 GHz bandwidth above -2 dB. CST simulation and measured results are in very good agreement. The bias tee will be a part of a new generation of on-chip THz detectors based on zero-bias Schottky diode and high electron mobility field effect transistor (HEMT).**

***Index Terms*—bias tee, broadband THz detectors, Field Effect Transistor (FET), room temperature THz detectors, S-parameters, Schottky Diode (SD), Terahertz (THz).**

I. Introduction

The electromagnetic spectrum between 0.1 to 10 Terahertz (THz) was commonly referred to as 'THz gap' for a long time until recently due to the absence of powerful sources and sensitive detectors. Meanwhile, ongoing progress closes the THz gap with more and more applications coming in reach such as spectroscopy, medical imaging, quality control, communications, space science, beam diagnostics and characterization applications to name few [1]. However, there is still a long way to go for THz electronics to the development of handy, cost-effective, robust and easy to use sources and detectors [2], [3]. Along with the development of active devices for the THz domain, new directions and developments in passive devices are also required in order to integrate THz systems on chip or systems in package. Room temperature operated broadband direct THz detectors have been developed for diagnosis and characterization of picosecond-scale pulses at particle accelerators [2]. Currently, the post-detection electronics is the limiting factor for these detectors. An efficient IF circuit is required to harness the full potential of these detectors. An IF equivalent circuit of Field Effect Transistor-based THz detectors has been derived in [4]. Similarly, Schottky diodes are well understood [5], enabling the development of matched IF circuitry for both. The ultra-broadband IF bias tee is one of the essential components for integrating THz detectors on chip.

We are thankful for cooperation between TU Darmstadt, Darmstadt, Germany and Mittelhessen University of Applied Sciences, Friedberg (Hesse), Germany for this project. Also grateful to Hesse ministry of science and culture for funding the position of Mr. Rahul Yadav.

The basic design principle of bias tee are very well described in the literature [6]. Ideally the bias tee is used to shoot the DC into the RF circuit, without affecting the RF path in the circuit. For integration of amplifier with the active THz detector (HEMT or Schottky diode) on chip, the bias tee will be required to power the amplifier and also to safeguard the RF circuitry without damaging the devices. In this paper, the stub concept is applied for the design of a novel double mirror stub (DMS) bias tee which provide the ultra-broadband isolation bandwidth.

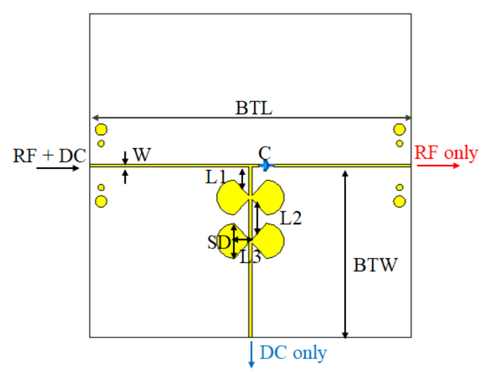

Fig. 1. Schematic diagram of the designed double mirror stub (DMS) bias tee

II. Design of DMS bias tee

The bias tee was first calculated theoretically [6] and then optimized using CST microwave studio.

The designed structure is shown in Fig. 1. The concept of double mirror stub was used to improve the RF blockage since mirror stubs act like a RF wall on both the sides of the transmission line and block RF to pass through it, while in case of the single stub the electric fields available on the other side will not completely vanish. Therefore the concept of double mirror stub was used to improve the isolation efficiency. Dimensions of the designed structure are shown in Table 1.

TABLE I
PARAMETERS OF FABRICATED STRUCTURE

Acronym	***Full Form***	***Dimensions*** (mm)
BTL	Bias-T Length	40
BTW	Bias-T Width	40
W	Transmission line width	0.5
SD	Stub diameter	6
L1	Distance from RF transmission line	4.93
L2	Distance between two stubs	7.4
L3	Distance from DC transmission line	2.75
C	Capacitor	-

The bias tee was milled on a 250 µm thick RO4350B substrate with 35 µm of copper cladding. The milled structure is shown in Fig 2. For the RF ports, 3.5 mm connectors with frequency range up to 26 GHz are used and for the DC port DC to 18 GHz SMA connector is used. The surface mounted device (SMD) capacitor of 47 µF (denoted with 'C' in Fig.1) was used on the RF only transmission line to block the DC voltage at the RF only port.

Both, time domain solver (TDS) and frequency domain solver (FDS) simulations have been performed to test the design and observe the response of the structure. The TDS uses Finite integration technique (FIT) to solve the Maxwell's equations, while the FDS uses Finite element method (FEM). The former is useful for investigating the large structures and on broader frequency bandwidth compared to later which is used for narrow bandwidth where discrete simulations at discrete frequencies are required.

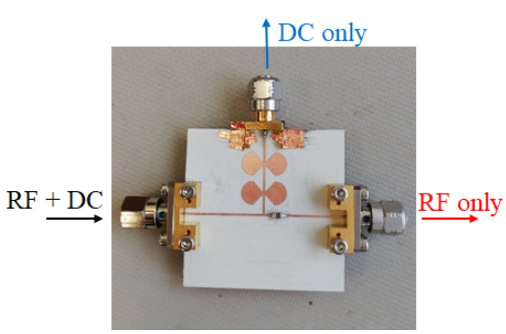

Fig. 2. DMS milled on RO4350B

The simulation result of S_{11} using FDS and TDS are shown in Fig 3. It is observed that between 5.5 to 10 GHz the TDS result have higher reflection compared to FDS results may be due different method of solving Maxwell's equations by software (different types of meshes).

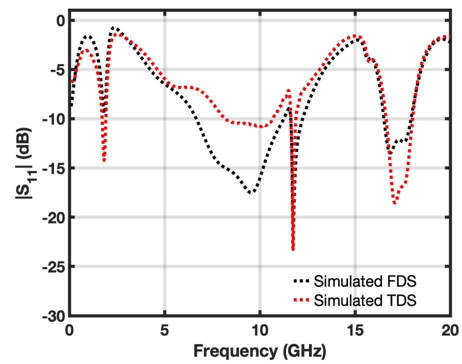

Fig. 3. Comparison of simulation result of S_{11} parameter using TDS and FDS

III. EXPERIMENTAL SETUP

The milled bias tee was characterized using a HP8722D network analyzer. Fig. 4 shows the experimental setup. The system was calibrated using OSLT (Open, Short, Load and Through technique) using the Agilent 85052D cal- kit to the end of the adapters of both cables.

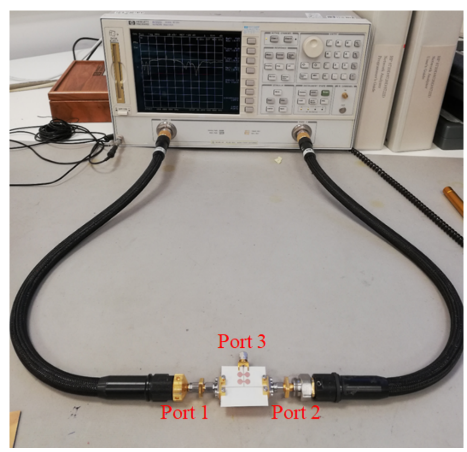

Fig. 4. Experimental setup for characterization of the bias tee

IV. RESULTS AND DISCUSSIONS

On RF ports (port 1 and port 2 as shown in Fig. 4), the 3.5 mm connector with DC-26 GHz frequency range was used. Below 2.5 GHz the DMS bias tee has higher return losses. So, the RF+DC is at port 1, RF at port 2 and DC at port 3. The perspective view of electrical field distribution is shown in Fig. 5 at 4 designated frequencies such as 2.5 GHz, 7.5 GHz, 12.5 GHz and 22.5 GHz. It can be seen in Fig. 5 that at 2.5 GHz and 12.5 GHz the DC is not completely blocked by stubs, that may be the reason of the nodge observed at that frequencies in Fig. 6,7,8 and 9. At 7.5 GHz the DC block is so significant as seen in Fig. 5, which can be verified in

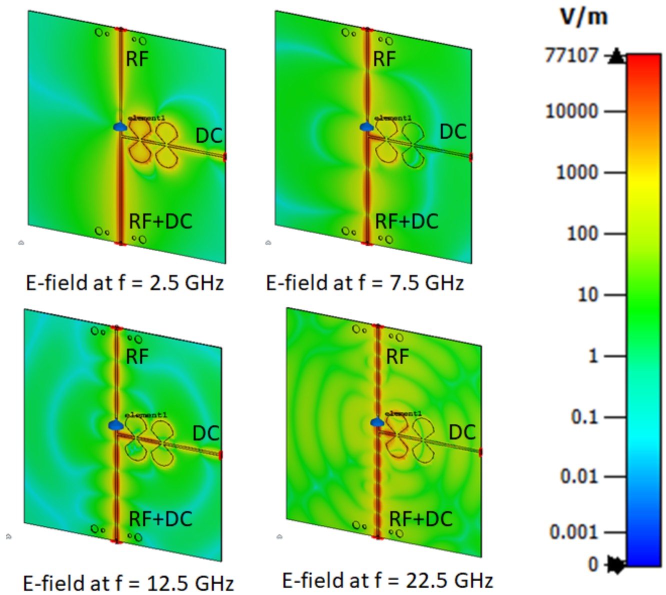

Fig. 5. Perspective view of simulated electric fields at different frequencies

the S_{11} (reflection) and S_{21} (transmission) in Fig. 7 and 8, respectively.

The simulation results from FDS are used to compare to measured results of the milled DMS bias tee for its characterization.

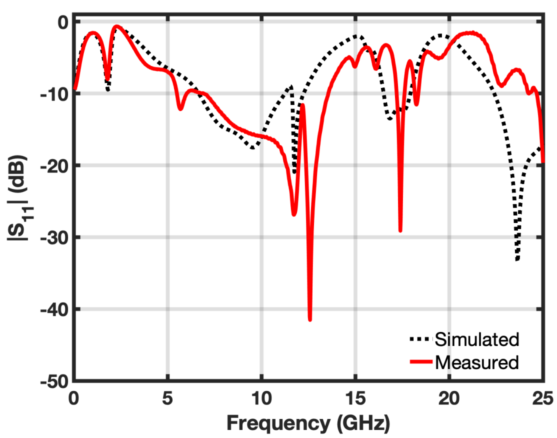

Fig. 6. Comparison of simulated and measured S_{11} (reflection) parameter of designed DMS

Between 5.5 to 13.5 GHz, the reflection is below -10 dB with minimum of -41.5 dB at 12.5 GHz, as shown in Fig. 6. The resonance-like features in the measurements are most likely due to the SMD capacitor soldering causing undesired reflections. The transmission above -2 dB is observed between 3.6 to 13.6 GHz with a slight deviation at 5.3 GHz and 12.1 GHz with minimum of -2.5 dB and -5 dB respectively. If we consider on an average, S_{21} provides a wide bandwidth of 10 GHz above -2 dB level as shown in Fig. 7.

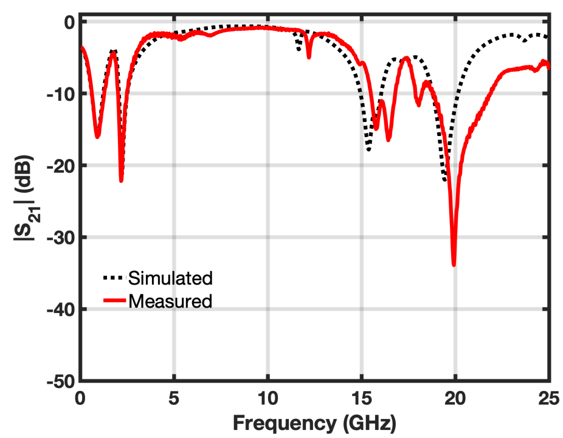

Fig. 7. Comparison of simulated and measured S_{21} (transmission) parameter of designed DMS

On DC port (port 3 in Fig. 4.) also referred to as isolation port, SMA connector with DC-18 GHz of frequency range is used. Being the isolation port, it should restrict the RF input and allow only DC to pass. A 14.45 GHz of bandwidth is observed for transmission (S_{31}) below -10 dB between 2.15 to 16.60 GHz, as shown in Fig. 8. Below -30 dB 8 GHz of bandwidth is obtained for S_{31}. Between 6 to 8 GHz approximately 10 to 16 dB of difference is observed between simulated and measured result because of the resolution limit of the vector network analyzer for measurement. The reflection bandwidth obtained is 13.1 GHz above -2 dB between 2.1 to 15.2 GHz (except for the peak at 12.1 GHz with -6.41 dB return loss, which can be due to the stubs), as shown in Fig. 9.

TABLE II
STATE OF THE ART WORK COMPARISON WITH WORK DONE IN PAST

Ref.	Frequency range	S_{11} **Bandwidth below -10 dB**	S_{21} **Bandwidth above -2 dB**	S_{31} **Bandwidth below -10 dB**	S_{33} **Bandwidth above -2 dB**
[7]	1-10 GHz	5.5 GHz	4.75 GHz	5 GHz	-
[8]	5-15 GHz	-	-	9 GHz	-
[9]	0-13 GHz	9.5 GHz	10.3 GHz	-	-
This work	0.1-25 GHz	8 GHz	10 GHz	14.45 GHz	13.1 GHz

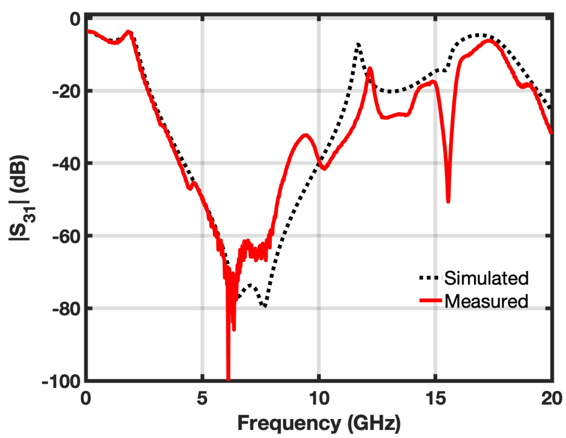

Fig. 8. Comparison of simulated and measured S_{31} for the isolation port

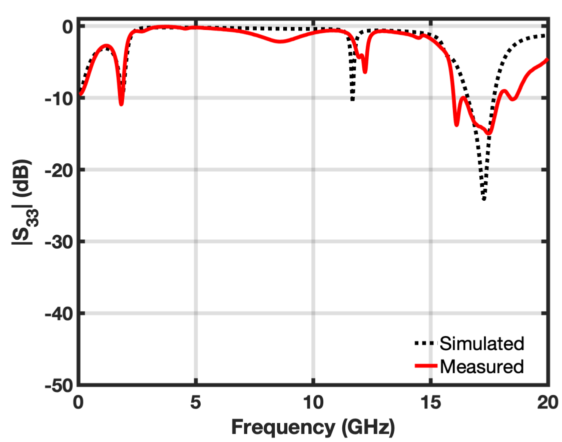

Fig. 9. Comparison of simulated and measured S_{33} for the isolation port

The simulated peak at 11.7 GHz is slightly shifted to 12.1 GHz in measured results as seen in Fig. 8 and 9, which can be due to stray RF coupling due to connectors.

V. CONCLUSION

A planar broadband bias tee has been designed for the integration in the IF circuitry of on-chip room temperature broadband THz detectors. An Isolation port with S_{31} of 14.45 GHz bandwidth below -10 dB and S_{33} of 13.1 GHz bandwidth above -2 dB has been demonstrated. The results of this work has been compared with previous work in the Table 2.

VI. ACKNOWLEDGMENT

Authors are grateful to Hesse ministry of science and culture for funding the position of Mr. Rahul Yadav. We are also grateful to Rogers cooperation for providing the substrate samples. We thank Mrs. Maria Elena Euken from University of Applied Sciences, Friedberg, Germany for helping out in the lab during the experiments.

REFERENCES

[1] D. M. Mittleman, "Perspective: Terahertz science and technology", Journal of Applied Physics, vol. 122, no. 23, pp. 230901, 2017.
[2] S. Preu, M. Mittendorff, S. Winnerl, O. Cojocari, and A. Penirschke, "THz autocorrelators for ps pulse characterization based on schottky diodes and rectifying field-effect transistors", IEEE Transactions on Terahertz Scienceand Technology, vol. 5, no. 6, pp. 922–929, 2015.
[3] A. Penirschke, et al.,"Compact quasi-optical schottky detector with fast voltage response", in 2014 39th International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz),2014, pp. 1–2.
[4] R. Yadav, S. Regensburger, A. Penirschke and S. Preu, "Microwave intermediate frequency equivalent circuit of GaAs high electron mobility field effect transistor terahertz detectors", in 2021 Fourth International Workshop on Mobile Terahertz Systems (IWMTS), 2021, pp. 1–6.
[5] R. Yadav, A. Penirschke and S. Preu, "Broadband Characterization of a Compact Zero-Bias Schottky Diode Detector with a Continuous Wave THz System," in Proc. IBIC'21, ser. International Beam Instrumentation Conference, no. 10. JACoW Publishing, Geneva, Switzerland, 10 2021,pp. 388–391.
[6] R. Sorrentino and L. Roselli, "A new simple and accurate formula for microstrip radial stub, "IEEE Microwave and Guided Wave Letters, vol. 2,no. 12, pp. 480–482, 1992.
[7] R. Dehbashi, H. D. Oskouei and K. Forooraghi, "A novel broad-band microstrip radial stub resonator used in bias-t application", Microwave and Optical Technology Letters, vol. 48, no. 9, pp. 1766–1770, 2006.
[8] N. Jana, M. K. Mandal, and R. Shaw, "An improved design of a bias teeusing a modified radial stub", 2019 IEEE MTT-S International Microwave and RF Conference (IMARC), pp. 1–4, 2019.
[9] N.-T. Kim, "Ultra-wideband bias-tee design using distributed network synthesis", IEICE Electron. Express, vol. 10, p. 20130472, 2013.