D-band Modulated Signal Generation using Photonics Techniques

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Abstract—**D-band communications are envisioned for the next frequency step forward to support the future back-haul networks. Beyond technology developments that aim to tackle circuits and systems, testing approaches also need to support the frequency upgrade of systems. This paper presents the photonics approach to generate modulated signals in the range 110–170 GHz. Typical performances that can be reached using standard lasers are discussed, as well as the measurement of error vector magnitude induced penalty in relation to the power-compression curve of a D-band amplifier under test.**

Index Terms—**Millimeter-waves, THz measurements, THz communications**

I. INTRODUCTION

FOR several years, the development of active circuits for amplification in the 140–170 GHz range has progressed significantly, requiring corresponding advancements in characterization tools. In addition to conventional linear characterization, linearity measurements using dual-tone signals and wideband signal are imperative to accurately evaluate the system-level performance of amplifiers. This paper briefly describes the development of a modulated signal analysis (MSA) technique for D-band measurements. This paper is supported by a presentation titled “Key enabling technologies for future wireless, wired, optical and satcom applications (KETCOM)” in an international workshop at the European Microwave week (EuMW, www.eumweek.com), Paris, France, on September 22, 2024. This workshop captures the latest research roadmaps and achievements on these topics from the European ecosystem, comprising industry, research, and academia.

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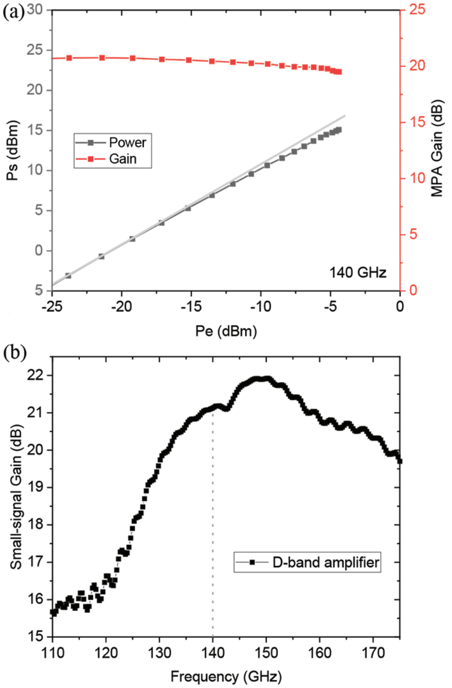

Fig. 1. (a) Small-signal gain of the DUT, in the whole WR6.5 (110–170 GHz) band. (b) DUT power curve at 140 GHz.

II. MODULATED SIGNAL ANALYSIS OF D-BAND AMPLIFIER

This section describes our investigation of MSA for the D-band measurements. In this investigation, we utilize the D-band transmitter (Tx) source established in the Chips JU project SHIFT. With this transmitter, we test the MSA using a non-linear circuit. This circuit is a medium power amplifier (MPA) working in the D-band. Figure 1a illustrates the typical gain of the device using the III-V technology. Figure 1b presents a typical compression curve of the amplifier at 140 GHz.

One of the main key performance indicators of an amplifier is its linear power level available throughout its operational lifetime. The P_{1dB} metric is typically used to evaluate the linearity of the circuit. Alternatively, the third-order intermodulation metric is used. The saturated power (P_{SAT}) is sometimes reported, but this provides only initial insights into amplifier linearity. In our study, the P_{1dB} was characterized and found to be approximately 12.5 dBm. In practical telecommunication scenarios such as back-hauling applications, amplifiers integrated into analog front-ends must handle advanced modulation formats like quadrature amplitude modulation (QAM). This necessitates a power back-off from P_{1dB} to achieve fully linear operation. This required back-off can vary depending on the circuit architecture and the specific modulation format employed.

III. MODULATED SIGNAL ANALYSIS SETUP AND MEASUREMENTS

For telecommunications applications, amplifier properties must often be evaluated over the entire channel defined by the standard. Consequently, new testbeds are required based on wideband signals instead of continuous-wave single tones. To assess the performances of the MPA for communication applications, we propose using a complex modulated signal injected into the device under test (DUT). At amplifier's output, any non-linear effect will degrade the quality of the constellation, which can be qualified by the error vector magnitude (EVM, %). The variation of the EVM with output power is an effective method for assessing the amplifier linearity, as EVM should remain constant if the amplifier is within in its linear regime.

To this end, we employ a reference transmitter (Tx in Figure 2) that generates a complex wideband modulation with a 140 GHz carrier frequency and a calibrated input power (P_{in}). The system uses optical techniques in coherent optical

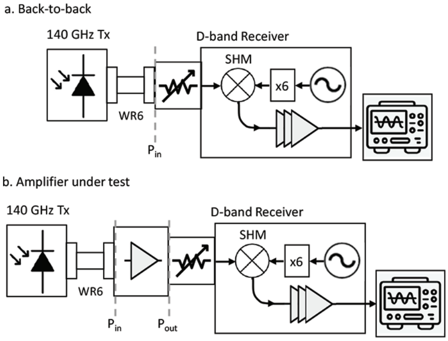

Fig. 2. (a) Back-to-back measurement in MSA analysis. (b) Evaluation of the EVM obtained using the amplifier under-test. SHM: Sub-harmonic mixer is used to down-convert the signal from 140 GHz to an intermediate frequency, further detected on a w wideband real-time oscilloscope. The attenuator is used to optimize the power injected into the receiver.

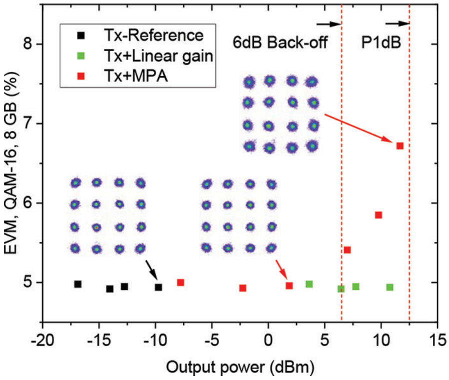

Fig. 3. EVM performances at 140 GHz. EVM of the reference Tx combined with the receiver (black). Expected EVM extrapolation of the amplifier linear gain at 140 GHz (green). Actual performance of the system with the amplifier under test (red). Dashed lines show the P_{1dB} and 6 dB back-off from P_{1dB}.

fiber communication systems. Initially, a set of two laser lines is used: one is I/Q modulated using a Mach-Zehnder modulator, and the other remains a continuous wave. These two lasers are coupled and amplified before being injected into the fast photodiode (Tx). A photomixing process occurs in at the fast photodiode, where the two lasers, detuned by 140 GHz, produce a D-band modulated signal at the photodiode. By utilizing an arbitrary waveform generator to create the I/Q base-band signals, both the modulation format and the baud rate can be adjusted. In this example, an 8 GBaud rate with 16-state QAM-16 was considered, resulting in a data rate of 32 Gbit/s. The main advantage of photonics over fully electronics techniques is the ease of modulation at the optical level and the frequency tenability, which can span the entire D-band.

This modulated signal is then used a test signal and the EVM evolution versus output power is shown in Figure 3. The black curve presents the EVM of the reference transmitter, while the green curve shows the expected EVM with a linear amplifier using the small signal gain illustrated in Figure 1. The red curve depicts the actual performance of the system with the amplifier under test. As expected, the red curve is shifted to the right, indicating that the MPA can provide more power than the reference Tx source. However, beyond 5 dBm at MPA output, a noticeable EVM degradation occurs before reaching the DUT's P_{1dB}. In this configuration, maintaining less than 0.5% EVM degradation requires a 6 dB back-off from P_{1dB}, while a 10 dB back-off from P_{1dB} results in almost no degradation.

IV. CONCLUSION AND OUTLOOK

Next, we plan to optimize the reference EVM levels obtained from the transmitter and study the transmitter's linearity to determine available linear range if P_{in}. Additionally, the capability of the developed testbed over the upper part of the D-band (from 140 to 170 GHz) will be evaluated. The MSA technique will then be applied to assess the performance of D-band amplifiers using BiCMOS technology, designed and fabricated in the Chips JU project SHIFT.

Yewulsew Manale Wodaje was born in Bahir Dar, 1994, Ethiopia. She graduated from Bahir Dar Institute of Technology, Bahir Dar University (BiT), Bahir Dar, Ethiopia, in 2018 (B.Sc. degree in electronics and communication engineering), in 2023 (M.Sc. degree in microelectronics engineering) and started working toward her Ph.D. degree at the Institute of Electronics, Microelectronics and Nanotechnology (IEMN), UMR-CNRS 8520, University of Lille, Villeneuve d'Ascq, France, since January 1, 2024 on the thesis entitled " Contribution to circuit design and advanced characterization for D-band communications applications".

Bachar Baridi received the master's degree in microelectronics from the Univeristé de Strasbourg, France, in 2023. His research interests cover the power amplifiers and linearization techniques. He is now working toward a Ph.D. degree at the Institute of Electronics, Microelectronics and Nanotechnology (IEMN), UMR-CNRS 8520, University of Lille, Villeneuve d'Ascq, France.

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François Danneville received the Ph.D. degree in electronics and the Habilitation à Diriger les Recherches from the Lille1 University of Sciences and Technology, Villeneuve-d'Ascq, France, in 1991 and 1999, respectively. Until 2000, he was an assistant professor with Lille1 University. He has studied the noise of III–V devices operating in linear and non-linear operations (in LNA, mixer, and oscillator). In 1998, on the aforementioned research topic, he made one year sabbatical as a visitor scientist in HP (nowadays Keysight Technologies), Santa Rosa, CA, USA. Since 2001, he has been a full professor with Lille University, where his research has focused on the small (large) signal and noise properties in high-frequency range (centimeter and millimeter waves) of advanced silicon technologies (CMOS and SiGe HBTs), including alternative architectures and circuit design. Since 2014, his research work has been focusing on the development of an ultralow-power silicon CMOS artificial neuron (published in *Frontiers in Neuroscience*, March 2017) and is currently focusing on the integration (scaling) of this new neuromorphic technology within neural networks. His research areas of interest (to cite a few) are biocomputing, smart visual and hearing sensors, electronic systems for neural recording and stimulation, and fluctuations and noise in artificial and biologic neural systems.

Pascal Szriftgiser received the Ph.D. degree in quantum physics from the Laboratoire Kastler Brossel, University Paris VI (Sorbonne University today), Paris, France, in 1996. The same year, as a researcher, he joined CNRS (Centre National de la Recherche Scientifique) at Laboratory PhLAM (Physique des Lasers Atomes et Molécules). Since 2012, he has been CNRS Research Director. From 2014 to 2021, he is the Leader of the Cold Atoms Group and Deputy Director of the Laboratory PhLAM from 2019 to 2021. Since 2021, he has been a PI of Contrat de Projet Etat Région (CPER) WaveTech@HdF, a consortium that brings together six research laboratories in Hauts-de-France country. He has authored or coauthored 137 publications in peer-reviewed international journals or conference proceedings. His expertise spans from cold atoms physics, quantum chaos, topology, and non-linear optics in optical fibers to high-speed coherent optical communications for THz applications.

Guillaume Ducournau was born in Clamart, France, in 1979. He graduated from ESIGELEC, Rouen, France in 2002 (Engineering degree), and received the Ph.D. degree from the University of Rouen, France, in 2005, on optical fiber communications. He has been with the Institute of Electronics, Microelectronics and Nanotechnology (IEMN), UMR-CNRS 8520, University of Lille, Villeneuve d'Ascq, France, since 2007. He is the Leader of the THz wireless communications activity with IEMN using optoelectronic THz photomixers, electronic receivers, THz instrumentation, and millimeter-wave (mmWave) characterization. He worked on several European projects: STREP ROOTHz 2010–2013, THoR H2020, GRAPH-X, TIMES (6G SNS), as well as the Marie-Curie TERAOPTICS network. At national level, he was the coordinator of the COM'TONIQ Project from 2014 to 2017 funded by ANR (INFRA 2013) dedicated to THz communications in the 300 GHz band, the ANR/DFG TERASONIC project for the use of THz photonics technologies and electrical solid-state technologies for THz communications, and SPATIOTERA for spatially distributed photomixers. He received the 2020 ISAP BEST PAPER award. He is involved in national France 2030 programs gathering several French laboratories under the "PEPR" programs funded by the ANR (Agence Nationale de la Recherche). In this framework, the FUNTERA project (6 partners) is investigating THz converters, while the SYSTERA project (12 partners) is dedicated to beyond 90 GHz systems for future networks. He also participates to the ST-IEMN common laboratory, and more specifically involved in the mmWave technologies characterization part, as in the JU SHIFT European program. He has authored or co-authored more than 180 publications in peer-reviewed international journals or peer-reviewed conferences proceedings and holds one patent. Professor Ducournau is serving as General Chair of the European Microwave Week in Paris, 2024, "Waves Connecting Europe."