Spectral Purity Evaluation of VNA Frequency Extenders to Enable Electronic Software-Based Power Control

De Martino, C.; Bueno Lopez, J.; Spirito, M.

DOI
10.1109/ARFTG57476.2023.10279333

Publication date
2023

Document Version
Final published version

Published in
Proceedings of the 2023 101st ARFTG Microwave Measurement Conference (ARFTG)

Spectral Purity Evaluation of VNA Frequency Extenders to Enable Electronic Software-Based Power Control

C. De Martino[1,2], J. Bueno Lopez[2], M. Spirito[2]

[1]Vertigo Technologies B.V., Delft, Netherlands
[2]Delft University of Technology, Mekelweg 4, 2628 CD, Delft, The Netherlands

Abstract — **In this paper, we present an experimental strategy to analyze the harmonic content of mm-wave frequency extenders using the VNA (absolute) power calibration step, without requiring spectrum analyzers and/or separate downconverters. The spectral purity of the upconverted band of the extenders is a key requirement to enable entirely software-based power control required for the accurate analysis of an (active) device under test.**

The proposed approach is based on the complementary response provided by the calorimeter-based power meter (i.e. VDI PM5) capable of integrating the entire spectral content of the waveguide band, in respect to the extreme frequency selectivity of the narrow-band mixer-based downconverter of the VNA. This complementary integration bandwidth response allows to compare the two results at each input drive level (at the power calibration setup, in-situ) and link the difference to the increased harmonic content contribution, with respect to the spectral content value at the saturation drive level, i.e. nominal manufacturer specified. The paper presents tests carried out in the WR10 (75-110 GHz) and WR6 band (110-170 GHz). The WR10 resulted in a harmonic contribution on the total output power of a maximum of 0.3 dB down to -33 dBc power back off from saturation level, and less than 1 dB down to -38 dBc while the WR6 the same parameter is less than 1 dB over the entire frequency band excluding the lower frequency points.

Index Terms — **mm-wave, frequency extenders, spectral purity, device characterization, large-signal, s-parameter.**

I. Introduction

The usage of the mm-wave frequency spectrum is gathering more momentum in several commercial/large volume applications due to several enabling capabilities, such as: large absolute available bandwidth at reduced relative occupancy, providing high data rates for telecom applications [1] and small wavelengths enabling high imaging resolution, with compact antenna sizes [2].

Nevertheless, the uptake of commercially viable mm-wave applications has to be followed/anticipated by an equal improvement/development of the technology modeling efforts [3], among others also in the non-linear response of the device. Measurement setups employed for device characterization and modeling, in the mm-wave range, make use of non-linear up-conversion chains to extend the frequency range of the instrument, i.e., frequency extenders in VNA test benches. Often frequency extenders lack automatic power control at the output test port, limiting the hardware controlling/leveling capabilities , required when the setup is employed in small and large signal measurements [4]. The often implemented solution, is to employ a (manual) attenuator before the coupler, as shown in Fig. 1, resulting in an operator-intensive and very slow procedure, especially when a power sweep, with a large number of points, is required.

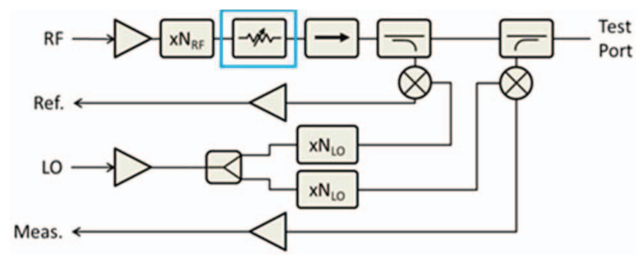

Fig. 1 - Internal scheme block of a frequency extender

Moreover, even when no power sweep is required (i.e., during small-signal S-parameter measurements of active device), considering the limited flatness of the frequency response of such systems, see Fig. 2, using the attenuator to ensure a small-signal device regime, would actually lead to a reduction of the dynamic range in several frequency points (usually on the edge of the operating band).

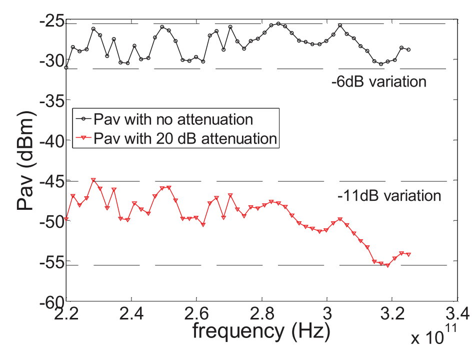

Fig. 2 - Variation of the measurement dynamic range across the frequency band due to the limited flatness of the frequency response and the use of the attenuator [5].

The authors have proposed in [5] a full electronic power level control, by modulating the power level at the input of the extender. While varying the input power level gives clear benefits, it is necessary to take into account the (possible) degradation of the nominal response of the multiplier in terms

2023 101st ARFTG Microwave Measurement Conference (ARFTG) | 979-8-3503-2345-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/ARFTG57476.2023.10279333

of its spectral harmonic rejection, which is optimized by the manufacturer when the multiplier is being operated at saturation power levels [6][7].
This paper presents a measurement strategy to evaluate the output harmonic content of the mm-wave extenders over its input/output power sweep range. The paper is organized as follows, in the first section a description of the measurement setup is provided. After a detailed description of the measurement procedure is given and finally, measurement results are shown for the WR10 waveguide frequency band (75-110 GHz).

II. Measurement Setup

The measurement setup, enabling automatic power control of the mm-wave power, is realized using a Keysight PNA N5224B, WR10 frequency extenders employing WR10 AMC-I multipliers and operating the entire system via the MMW-STUDIO software provided by Vertigo Technologies [8]. A simplified scheme block of the system is in Fig. 3. MMW-STUDIO, employs three calibration steps to accurately set a user-defined power level at each of the output ports of the mm-wave extenders (i.e., port 1 and port 2) during the measurements. The various calibration steps and power control performance have already been presented by the authors in [4][5][9].

The calorimeter-based power meter, VDI Erikson PM5, which is used during the power calibration step, performed by MMW STUDIO, has also been used to measure the total spectral power at the output of the extenders thanks to its large measurement bandwidth (0.075-3 THz) [10].

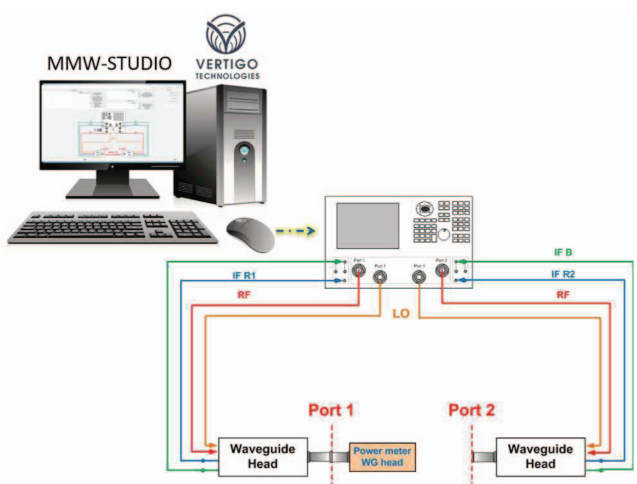

Fig. 3 - Measurement setup used, controlled by MMW-STUDIO.

III. Measurement procedure

After completing the power calibration, the repeatability of the two instruments (i.e., trace noise) is evaluated by comparing the spectral power at every (cal) frequency point (i.e. acquired with the VNA) with the average power acquired, during CW mode operation, by the PM5. Since the test is carried out at the same power level used during calibration, the only effect acquired during this test is the trace noise which will be used to define the experiment noise floor.
The result of the test is shown in Fig. 4 (Top), where the two measurements are compared and Fig. 4 (Bottom) where the difference is depicted, explicitly calculated considering the value expressed in dBm. The test is performed at the nominal power of the extender. i.e., 15 dBm.
Before proceeding with the next steps it is important to make the reader aware of the information provided by the two different ways of measuring the power, presented in Fig. 4 in order to allow a better understanding of the experiment.

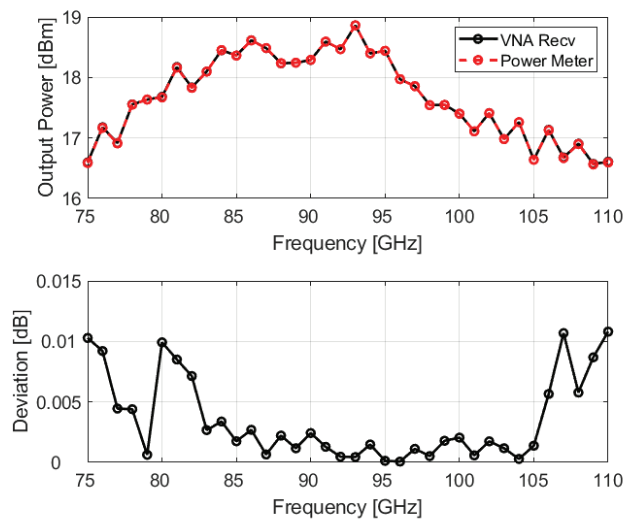

Fig. 4 – (Top) Measurement of the output power level of the extender using the VNA receiver (solid black) and the PM5 (dashed red); (Down) Difference between the two measurements.

A calorimeter-based power meter, as the PM5, by its nature, is a true averaging detector which means that the power value measured represents the integrated power spectral density of the input signal. Using the narrow band mixer-based receiver of the VNA, the power measured can be considered spectral power. This means that when considering a signal with a non-continuous spectrum content, as is the case of the signal out of an extender where only harmonic related tones (and few, low power, non-harmonically related tones) are present, as sketched in Fig. 5, the VNA is capable of isolating only the tone of interest. A first-order evaluation of the spectral purity of the signal out of the employed extender can then be performed by repeating the test presented in Fig. 4 decreasing the extenders' output/input power. One of the limitations that have to be considered is the limited dynamic range of the PM5 compared to the VNA one which does not allow the measurement to go below ~-35 dBm.

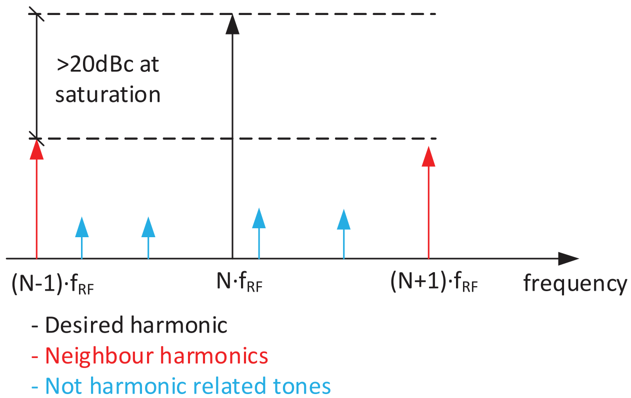

Fig. 5 - Typical output spectral content of a frequency extender.

Moreover, the dynamic range of the power meter is divided into 4 different ranges (0.2, 2, 20, and 200 mW) that need to be chosen based on the power level of the measurement. To overcome this limitation the proper range is automatically set, before every measurement point, based on the knowledge of the expected output power available after the calibration procedure performed by MMW-STUDIO.

IV. Measurement results

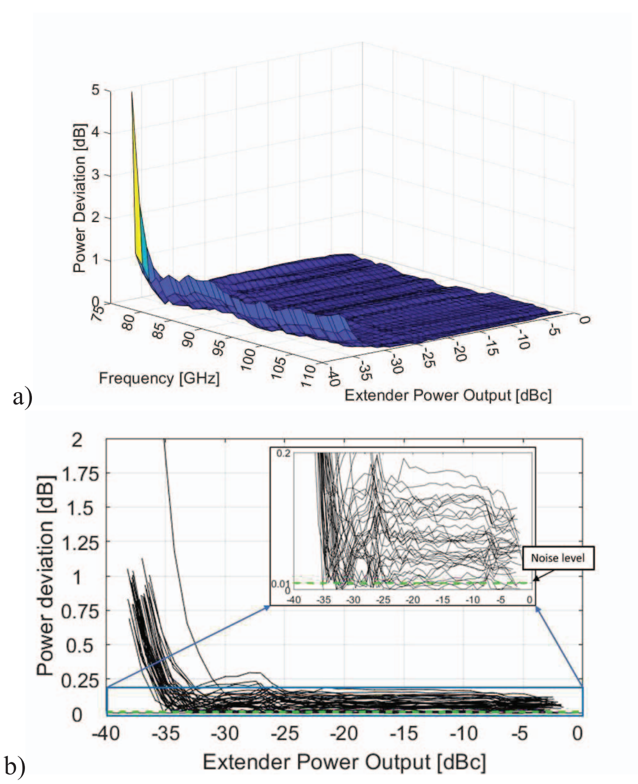

Fig. 6 - Difference between the total spectral power and the single-tone power in 3D visualization (a) and 2D visualization (b), in the case of WR10.

Note, when employing different ranges of the PM5 also a different time delay is used to comply with the different settling times of the instrument as indicated by the manufacturer [10].

Measurements were performed on the WR-10 waveguide band frequency extenders calibrating the VNA on 36 frequency points in the band (every 1 GHz). The measurement is executed by sweeping the power output from -20 to 15 dBm with a 1 dB step over the frequency points defined during calibration.

Fig. 6 shows the deviation between the total spectral power, measured using the power meter, and the power of the fundamental tone, measured using the VNA power calibrated, across the frequency band and versus the spectral output power. Excluding the edge of the operating bandwidth (i.e. 75 GHz) where the extender could show lower performance, the results show a deviation of a maximum of 0.3 dB until -33 dBc and less than 1 dB until -38 dBc.

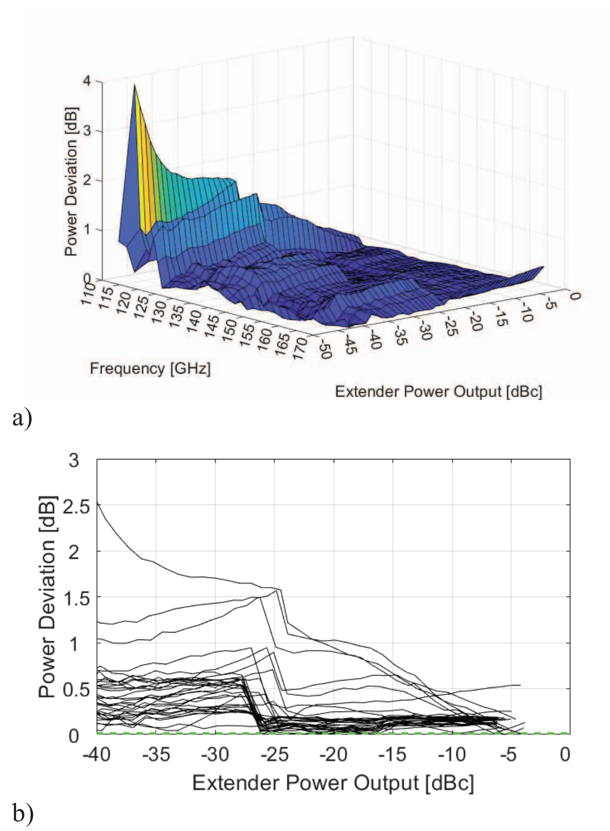

Fig. 7 – Difference between the total spectral power and the single-tone power in 3D visualization (a) and 2D visualization (b), in the case of WR6.

Having ~35 dB of variation with a good spectral purity allows for performing large-signal measurements and seeing all the figure-of-merit of the device under test in a non-linear regime without being compromised by the impurity of the feeding signal. Moreover, although in the case of S-parameter measurement, the power required could force the extenders to work in a regime where it cannot provide a pure feeding signal (i.e. below the purity threshold) the DUT is working in a linear regime and an eventual multitone input signal does not impact the measurement results.

In Fig. 7 the power deviation measured on VDI WR6 extender is shown. It is possible to observe that in this case, the deviation is more than in the previous case but still is less than 1 dB discarding the lower frequency points.

V. Conclusion

This paper presents a procedure to evaluate the output spectrum purity of the mm-wave frequency extenders when a software input power control is employed. The procedure makes use of the VDI Ericson PM5 for the total spectral power measurement and MMW-STUDIO to enable the VNA to measure the power of a single signal spectral component thanks to its vector power calibration. Measurement of the WR-10 and WR6 frequency extenders has been presented. The WR10 shows a harmonic contribution on the total output power of a maximum of 0.3 dB until -33 dBc and less than 1 dB until -38 dBc. The WR6 shows an higher contribution but remaining less than 1 dB on the entire band and until -40 dBc excluding the frequency points close to the lower edge of the frequency band.

References

[1] X. Yu et al., "Exploring THz band for high speed wireless communications," 2016 41st International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz), Copenhagen, 2016, pp. 1-2.

[2] P. Hillger, J. Grzyb, R. Jain and U. R. Pfeiffer, "Terahertz Imaging and Sensing Applications With Silicon-Based Technologies," in IEEE Transactions on Terahertz Science and Technology, vol. 9, no. 1, pp. 1-19, Jan. 2019.

[3] D. Schreurs and K. U. Leuven, "State-of-art, challenges and future directions in large signal measurements for active device modeling," *2010 IEEE MTT-S International Microwave Symposium*, Anaheim, CA, USA, 2010, pp. 1210-1213, doi: 10.1109/MWSYM.2010.5515304.

[4] C. De Martino, L. Galatro, R. Romano, G. Parisi and M. Spirito, "Hardware and Software Solutions for Active Frequency Scalable (Sub)mm-Wave Load–Pull," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 9, pp. 3769-3775, Sept. 2020, doi: 10.1109/TMTT.2020.3005178.

[5] L. Galatro, S. Galbano, A. Santaniello and M. Spirito, "Power control for S-parameters and large signal characterization at (sub)-mmWave frequencies," *2015 85th Microwave Measurement Conference (ARFTG)*, Phoenix, AZ, USA, 2015, pp. 1-4, doi: 10.1109/ARFTG.2015.7162903.

[6] https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/ZCxxx_dat-sw_en_3607-1471-22_v1700.pdf

[7] https://vadiodes.com/images/Products/VNA/Product_Manual/VDI-707.1-VNAx-Product-Manual.pdf

[8] https://vertigo-tech.com/wp-content/uploads/2019/07/4T-024_final.pdf

[9] C. De Martino, Z. Hu, L. Galatro, G. Sarris and M. Spirito, "Power level control of mm-wave test benches for accurate small and large-signal DUT measurements," *2016 88th ARFTG Microwave Measurement Conference (ARFTG)*, Austin, TX, USA, 2016, pp. 1-4, doi: 10.1109/ARFTG.2016.7839723.

[10] https://vadiodes.com/images/Products/PowerMeter/PM5manual/VDI-724.1_PM5B_Manual.pdf