Pushing the limits: The Future of Wideband Vector Signal Generators

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[Summary] As the wireless technology evolves, so does the need for more powerful and precise testing tools in the world of communications. That demands higher data rates, sensing and complex processing. Enter the future of wideband vector signal generators (VSGs) – the unsung heroes of signal generation that are pushing the boundaries of processing speed, bandwidth, and accuracy. With advancements in digital signal processing, VSGs are not only handling wider frequency ranges but also accommodating the increasingly complex modulation schemes of modern wireless systems. From 5G and beyond to radar and satellite communications, superior frequency hopping, these cutting-edge devices are redefining the possibilities, enabling engineers to stay ahead in an ever-demanding tech landscape.

1 Introduction

The demand for wideband vector signal generators is indisputable. This is because of unique demands, like generating multiple communication systems simultaneously, simulating complex environments, enabling high-bandwidth telecommunication, superior frequency hopping patterns, and higher-resolution radars.

The main challenge lies in developing new fundamental technologies to enable such an instrument.

In this paper, we present technologies and techniques including Digital communication links, DSP, Processing speed, Calibration techniques, Digital communication standards, Powerful FPGAs, high-speed and high-resolution DACs, small node CMOS semiconductors, synchronization techniques, and phase and magnitude stability.

2 Technology

A system that can generate 10 GSymbol/sec with a 16-bit resolution with real-time DSP processing power for filtering, equalization, and power control is demonstrated in this article.

At the core of every advanced wideband vector signal generator lies a high-speed DAC architecture[1]. There are multiple ways to achieve high-speed DACs with high resolution (16 bits).

(1) Single DACs, require smaller transistor technology to reduce the parasitic capacitance effect. This comes also with lower power.

(2) Multichannel DACs, using external I/Q modulators which feature more than double the speed using the same DAC technology. This method requires complex synchronization and calibration.

(3) Hybrid DAC architectures combining different DAC technologies better suit different frequencies and power requirements.

A high-speed digital circuit is required to stream the generated data. JESD204C can achieve speeds up to 32 Gbps/lane. PCIe 5 and PCIe 6 support 32 GTransfer/s and 64 GT/s[2]. PCIe 5 can reach up to 64 GBytes/s for an x16 connection. Although PCIe is not directly used with DACs it can serve as a backend for streaming. Multichannel architecture is scalable and provides more bandwidth than single channel.

FPGAs are widely used for high-speed DAC interfaces, but the target applications of wideband vector signal generators spike the demand for powerful DSPs. This demand puts significant pressure on offloading well-defined tasks such as interpolation from FPGA to ASIC chips often integrated into the DAC chip. Another opportunity in the future is to integrate an AI model to regenerate samples instead of interpolation to improve signal purity.

It must be mentioned that for streaming signals using OFDM or similar complex modulation schemes, the IFFT functionality must be offloaded from the OS to meet timing criteria. For Beam steering and MIMO applications, a multichannel phase coherent VSG is required. From the RF point of view, a wideband vector signal generator with a wide tuning range from a few MHz to mm-wave frequencies poses a challenge in filtering and maintaining signal purity. New techniques must be developed to reduce unwanted spurs,

images, or harmonics. To this end, active calibration and adjustment can be implemented with feedback to keep the device running in an optimal condition. All this must be done while keeping magnitude and phase stable with temperature drift. Filtering technology must be also pushed to the limits for mmwave frequencies.

Developing hardware that can work on mm-wave frequencies at a lower cost that meets requirements can be challenging.

An example of a 60 GHz filter mounted on a PCB in Figure 1 demonstrates a BPF from 50-60 GHz mounted on a PCB using chip-on-board technology.

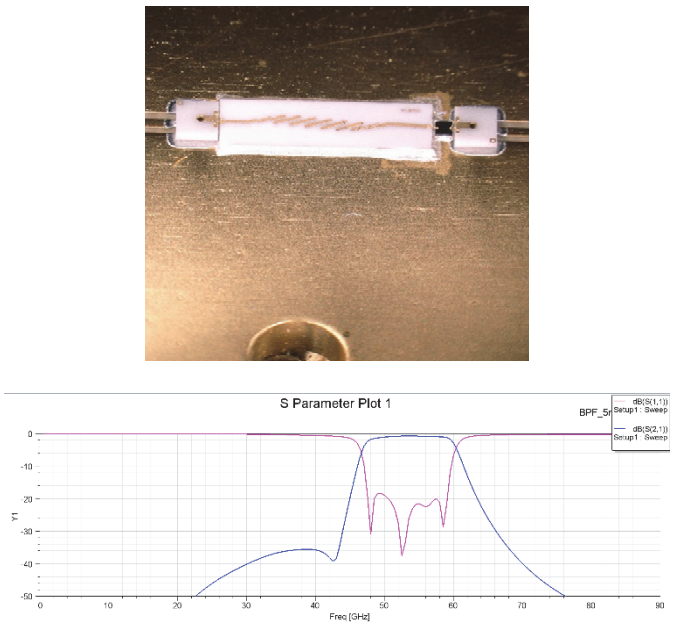

Figure 1 Anritsu BPF 50-60 GHz on a 5 mil Substrate on PCB

3 Calibration

Starting with baseband, multichannel high-speed DACs must be synchronized and calibrated for magnitude and phase.

This is also a key parameter for multi-channel VSGs to test multiple applications including MIMO.

I/Q imbalance is a key parameter that must be minimized, especially for wide bandwidth communications. An accurate and efficient method to measure I/Q Imbalance calibration across a wide band is to generate a single sideband multitone signal and evaluate the image rejection. Figure 2 shows performance before self-correction. It must be noted that this kind of correction is done internally in the instrument to maintain repeatability and preserve performance. This technique relies fundamentally on calibrated traceable power sensors internal to the instrument.

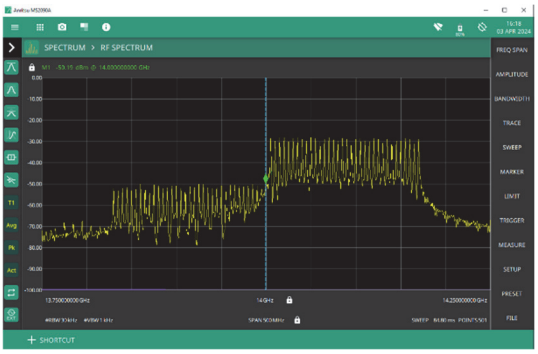

Figure 2 Single-side multitone generated signal showing 20 dBc image rejection before Calibration.

After correction, a multitone image is improved by more than 15 dB. It is also demonstrated that at 130 GHz a 40 dB of image rejection can be maintained for wideband signals.

This measurement has a strong correlation with EVM on a single carrier.

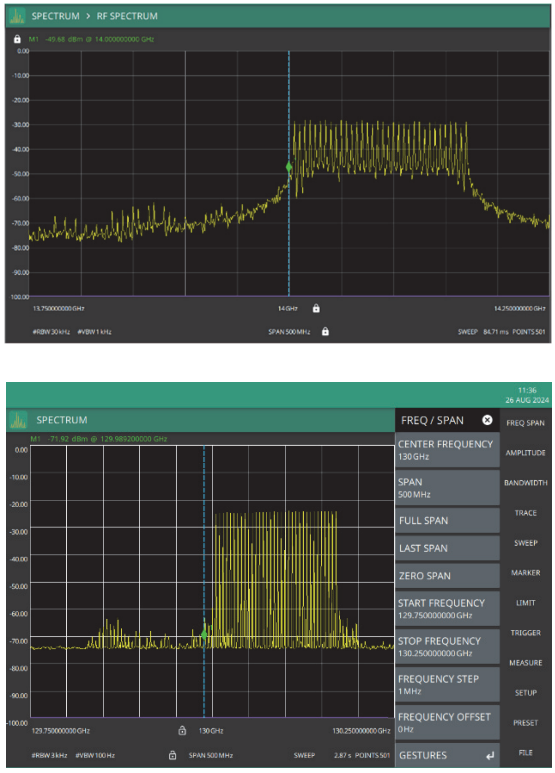

Figure 3 a) Image rejection improvement at 14 GHz, b) Image rejection at 130 GHz

Amplitude flatness is another critical factor in generating vector-modulated signals. It has a direct impact on a single-carrier modulated signals. Ideally, signals at different frequencies must be at the same power levels to reduce the DSP power and improve dynamic range. Figure 4 demonstrates a 10 GHz signal before and after flatness correction.

It must be noted that adjusting power levels requires a continuous adjustment of flatness correction, this makes it

challenging to do preprocessing ahead of time. Hence, the demand for DSP flatness correction for instant adjustment is necessary.

The calibration techniques we utilized enable utilizing VSGs to evaluate high-end receivers. Specifically at multiple TX planes and frequencies the VSG is calibrated to test the receiver at different stages. This provides improved overall calibration and performance understanding of the receiver.

Receiver testing is frequently limited by the quality of the transmitter, even loopback tests are limited as it may not be clear whether the TX or RX is the one limiting the performance. This TX plane calibration approach separates the TX from the RX performance.

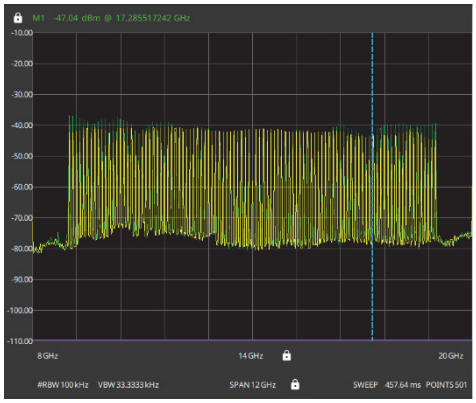

Figure 4 10 GHz signal before correction (green) and after correction (yellow)

4 Measurement

The quality of EVM on a single carrier signal demonstrates the performance of the hardware of the device and its calibration[3]. Testing using OFDM signals will not show the flaws of magnitude distortion of the instrument. This is because OFDM is immune to this distortion as it relies on multiple narrow-band carriers. On the other hand, OFDM can test the dynamic range.

Figure 5 demonstrates a 64 QAM single carrier EVM performance at 42 GHz with 5 GSps occupying 6.7 GHz of analog BW.

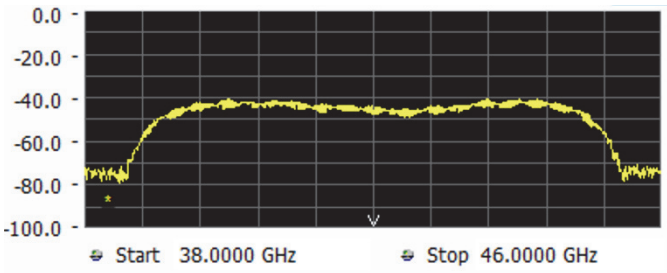

Figure 5 single carrier 64 QAM, 5 GSps at 42 GHz.

At 145 GHz, a signal quality of EVM=3.4% is demonstrated using a loopback measurement. From the constellation, it is evident that the degradation is dominated by the signal-to-noise ratio in Figure 6. This measurement includes both transmitter and receiver performance.

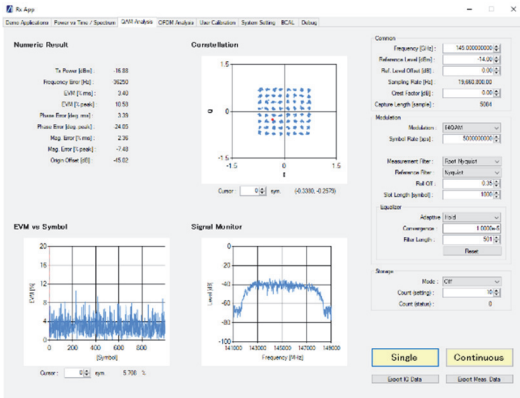

Figure 6 EVM measurement for multiple BWs and carrier frequencies

Upon measuring signal quality at different BWs and carrier frequencies it is more evident that pushing the limits of multi-GHz of modulation BW can be achieved at higher-order modulation schemes, Table 1 demonstrates true device performance using single carrier test signals at frequencies across multiple frequency points.

Table 1 EVM measurement for multiple BWs and carrier frequencies.

Configuration	EVM
64 QAM, 2.5 GSps @ 14 GHz	0.9%
64 QAM, 5 GSps @ 14 GHz	1.7%
64 QAM, 10 GSps @ 14 GHz	2.2%
64 QAM, 5 GSps @ 42 GHz	1.9%
64 QAM, 5 GSps @ 145 GHz	3.4%

5 Conclusions

This paper demonstrates the world-class performance of a wideband vector signal generator. The data shows exceptional accuracy (16 bit), low EVM, and seamless operation

across broad frequency ranges (from MHz to SubTHz).

By achieving such high levels of accuracy and fidelity, we are not only advancing the capabilities of current communication systems but also setting the stage for future innovations. This represents a significant leap forward in technology, showcasing the potential to drive further breakthroughs in a wide range of high-performance applications.

References

1) X Li, L Zhou, A survey of high-speed high-resolution current steering DACs[J]. J. Semicond., 2020, 41(11): 111404. doi: 10.1088/1674-4926/41/11/111404.

2) Lynch, D. P., Buehrer, R. A., & McDonald, J. F. (2023). PCI Express 5.0 and 6.0: Evolution of High-Speed I/O for Modern Computing. Journal of Solid-State Design and Engineering (JSDE).

3) Brown, Dustin & Rahmat-Samii, Yahya. (2023). Error Vector Magnitude as a Performance Standard for Antennas in the Millimeter-Wave Era: Part 1: Metric comparisons and measurement concepts. IEEE Antennas and Propagation Magazine. PP. 2-11. 10.1109/MAP.2023.3272838.

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