WHITE PAPER

4 Tips for 5G New Radio Signal Creation

Accelerate Design Validation for 5G NR

The promise of 5G technology is faster and more reliable communications. To enable mobile broadband communications, 5G uses existing and new technologies to achieve extreme data throughputs. However, these technologies introduce new test demands, including testing at millimeter-wave frequencies, wider channel bandwidths, and complex multi-antenna configurations.

Testing base-stations and mobile terminal transmitters and receivers begins with simulating 5G New Radio (NR) standard-compliant signals. To accurately simulate signals, test equipment must support channel coding and multi-antenna support and must allow you to manipulate a variety of signal parameters in multiple combinations to support complex test setups. Plus, you need metrology-grade reference signals to see true device under test characteristics. A robust test system supports generating test signals for a variety of test scenarios, from component characterization, design verification, and pre-conformance, to volume production testing.

New technologies that include 5G NR will require you to think differently about how you design and test devices. Here are 4 tips to help you successfully generate 5G NR test signals and get your designs to market faster.

KEYSIGHT TECHNOLOGIES

Tip #1: Simplify 5G Test Waveform Creation

The 3rd Generation Partnership Project (3GPP) specifies 5G NR test requirements for both user equipment (UE) and base stations (gNB). Table 1 illustrates the Technical Specification (TS) for UE and gNB minimum test requirements and conformance tests. The conformance testing documents specify the measurement procedures. The testing method consists of conducted tests, radiated tests, or a hybrid for the various frequency ranges.

Device	Minimum Requirements	Conformance Tests		Note
UE	TS 38.101	Conducted tests	TS 38.521-1	FR1
		Radiated tests	TS 38.521-2	FR2
		Conducted/ Radiated	TS 38.521-3	Interworking operation
gNB	TS 38.104	Conducted tests	TS 38.141-1	FR1
		Radiated tests	TS 38.141-2	FR1 and FR2

Table 1: 3GPP technical specification for 5G NR test

Each document specifies the transmitter characteristics, receiver characteristics, and performance test requirements. Additionally, Part 1 represents conducted tests and Part 2 represents radiated tests. Part 3 is for NR UE interworking between Frequency Range 1 (FR1, sub-6 GHz) and Frequency Range 2 (FR2, millimeter wave frequencies), or NR and LTE.

Configure Standard-Compliant Test Signals

To perform conformance tests, 3GPP identifies test signals for specific test cases. For example, 3GPP defines the Test Models (TM) for 5G NR gNB transmitter tests and the Fixed Reference Channel (FRC) for 5G NR gNB receiver tests in TS 38.141. The physical channels set up for tests needs to be based on the specification, including logical channels, resource allocation, payload data, bandwidth parts, control resource sets, cell-specific settings, and RF parameters. Each test signal has more than 50 adjustable parameters with relevant bandwidths and numerologies (sub-carrier spacing). Test equipment supporting pre-defined, standard-based conformance test setups can save setup time and give you confidence that your measurements are standard-compliant.

Accelerate Test Setups with Pre-Configured Setups

Figure 1 shows the 5G NR TM1.1 for FR1. Graphical display for the entire Radio Frame is located at the bottom-left corner. The x-axis represents the slot based on current numerology and the y-axis represents the resource block (RB) value. The colors represent the different channel type used in the frame – green represents a downlink shared channel (DL-SCH) and light green represents downlink control information (DCI). The detailed RB mapping appears at the bottom-right corner, including the demodulation reference signal (DMRS) in red, and the physical downlink shared channel (PDSCH) in green. The pre-configured setups help you generate 3GPP 5G NR standard-compliant signals for testing gNB, UE transmitters, and receivers quickly and easily as shown in the upper-right.

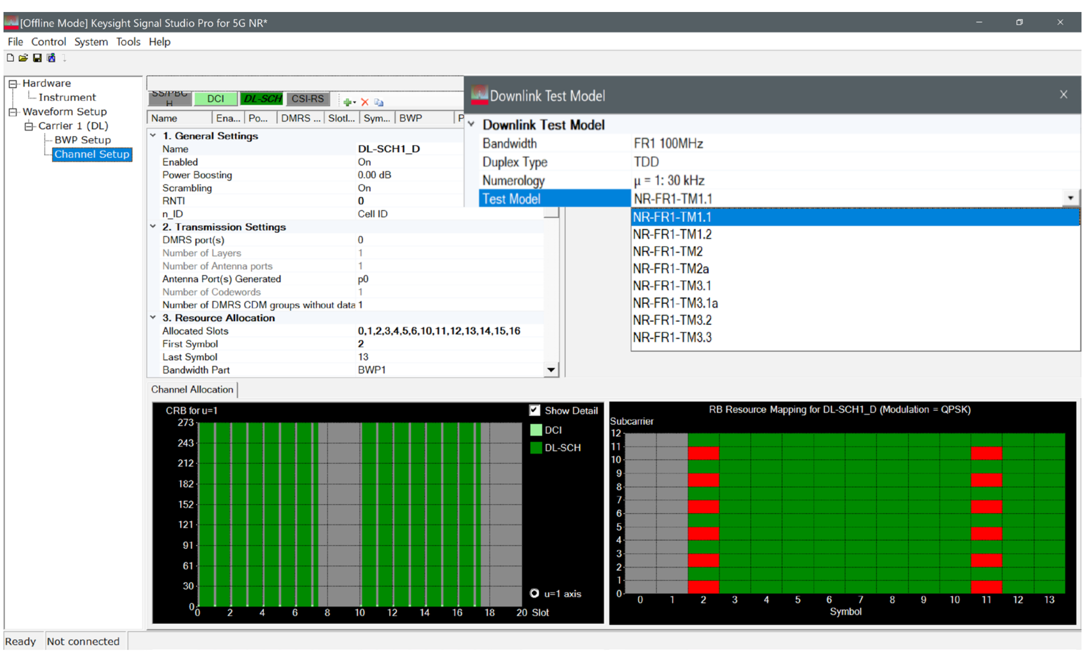

Figure 1: 5G NR TMs configuration with N7631C Signal Studio for 5G NR

Figure 2 illustrates the uplink FRC for gNB receiver testing. With a pre-configured tool, a test engineer can simply select a test type such as receiver sensitivity and in-channel sensitivity, or dynamic range for a specific test case, then choose an FRC with the specified sub-carrier spacing, number of resource blocks, modulation coding scheme, and coding rate.

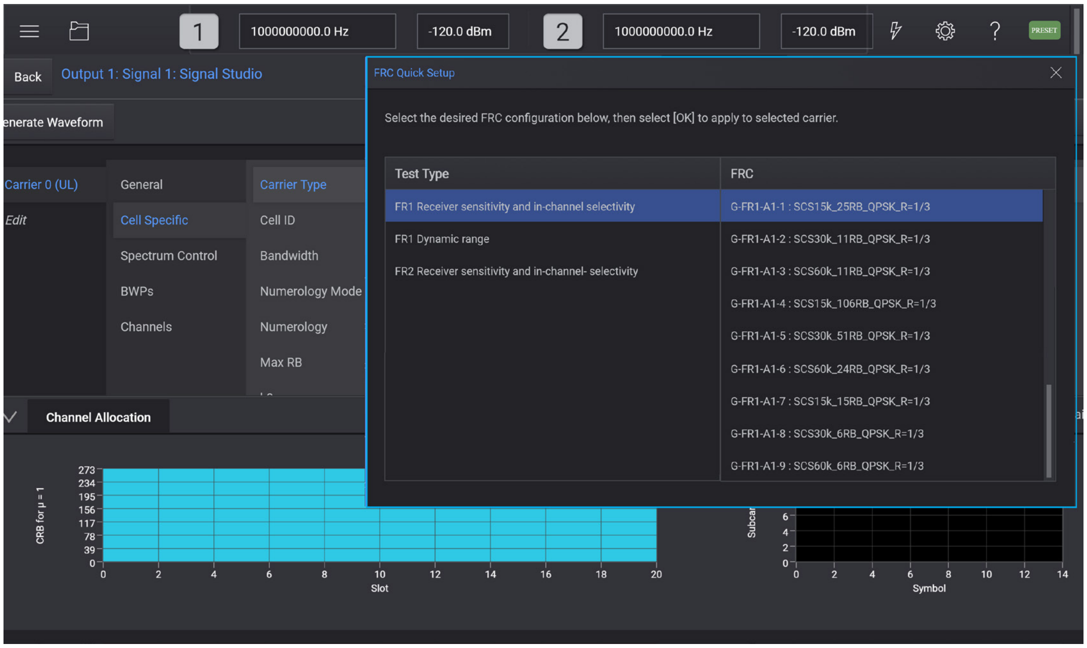

Figure 2: 5G NR FRC configuration with PathWave 5G NR signal generation embedded user interface

Tip #2: Evaluate the 5G NR Waveform

In modern wireless communications, modulation schemes are becoming more complicated. Complex modulated signals result in a higher peak-to-average power ratio (PAPR) which may lead to higher nonlinear distortion for devices under test such as amplifiers and mixers. Therefore, to extract useful power-related information from complex signals, you need a statistical analysis of the power levels.

An Essential Step to Generate a Modulation Signal

If you are an audiophile, you get high-Res audio music to test the performance of your sound system. Before doing that, you need to know the characteristics of the music. Otherwise, loud sound can cause the system damage or the sound distortion.

Power Complementary Cumulative Distribution Function (CCDF) curves characterize the probability of a signal peak being above the average power level and provide critical information such as the peak-to-average power ratio (PAPR). The CCDF helps engineers understand the probability of a given signal creating nonlinearities in a component and how much back-off may need to be applied to avoid clipping the signal peaks. When you simulate a digital modulation signal using a signal generator, you need to ensure that the output signal will not be saturated by the signal generator.

Gain Compression of a Signal Generator

If the output signal of the signal generator is saturated, it impacts not only the output power level accuracy, but also the modulation quality due to amplitude compression. For a high PAPR signal, the amplitude level setting on a signal generator cannot be greater than the maximum output power (i.e. peak envelope power, PEP) of the signal generator minus the PAPR.

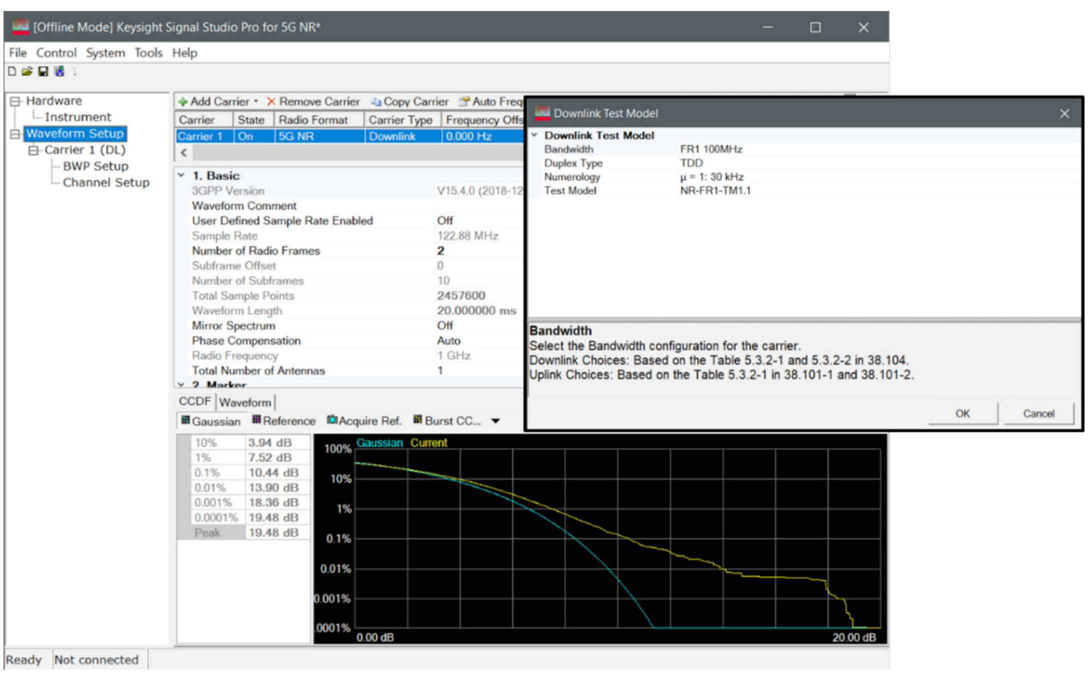

Figure 3: CCDF plot for 5G NR FR1 downlink TM1.1 with a 100 MHz signal bandwidth

Figure 3 shows the 5G NR FR1 downlink signal waveform simulation with 100 MHz bandwidth using the Test Model (TM) 1.1. The PAPR of the waveform is up to 19.5 dB. If the maximum output power of the signal generator is +20 dBm. The maximum amplitude setting (average power) you can go with the signal generator is +0.5 dBm (20 – 19.5 = 0.5). This prevents the signal generator's power amplifier from being saturated. Signal generators require a very linear output section with less distortion for 5G signal generation.

Why is the high output power of signal generators critical for mmW measurements?

5G FR2 mmW operating bands have wider channel bandwidths for enabling 5G's promise of extreme data rates, but it also exposes a signal propagation issue - excessive path loss. To overcome the path loss, 5G NR uses phased array antennas increase the antenna directivity and gain. This results in the need for OTA tests. To overcome excess path loss in cables, switching, and free space radiation (OTA), a signal generator needs higher output power levels to compensate for the loss. A signal generator suitable for 5G testing must have a linear output section, less distortion, and low phase noise at high output levels. These factors are key to making accurate measurements at mmW frequencies, and to ensure that errors are not coming from the signal generator itself.

Tip #3: Minimize Channel Response for Wide Bandwidth Signals

Enhanced Mobile Broadband (eMBB) is one of the use cases defined for 5G. It uses existing and new technologies to achieve the expected extreme data throughputs, including wider channel bandwidths, carrier aggregation, a high modulation density, and multiple antennas. The 5G NR maximum channel bandwidth is 400 MHz for FR2 and the maximum aggregated channel bandwidth (contiguous) is up to 1.2 GHz. The channel flatness decreases as the channel bandwidth typically increases. Table 2 represents the maximum channel and aggregated bandwidths of the new wireless standards.

Standard	Revision	Maximum Channel Bandwidth	Maximum Aggregated Channel Bandwidth (Contiguous)
3GPP 4G	LTE (R8)	20 MHz	NA
	LTE-A (R10)	20 MHz	100 MHz
	LTE-A Pro (R13-14)	20 MHz	640 MHz
3GPP 5G*	NR FR1 (R15)	100 MHz	400 MHz
	NR FR2 (R15)	400 MHz	1200 MHz
* 3GPP TS 38.521-1/2 V15.0.0 UE conformance specification, radio transmission and reception			

Table 2: The maximum bandwidths of the 3GPP standards

Internal Channel Correction

Most new vector signal generators have an internal calibration routine, also referred to as factory calibration, that collects correction data for both the baseband and RF magnitude, along with phase errors over the entire RF frequency and power level range. The correction data includes the parameters of the correction filter applied to baseband waveforms. Correction processing is implemented in real-time by a digital signal processor (DSP).

Figure 4 shows measurement results of a 5G NR signal with 400 MHz bandwidth with internal channel correction enabled. The frequency response for amplitude is less than ±0.1 dB and 0.5 degrees for phase which represents excellent performance.

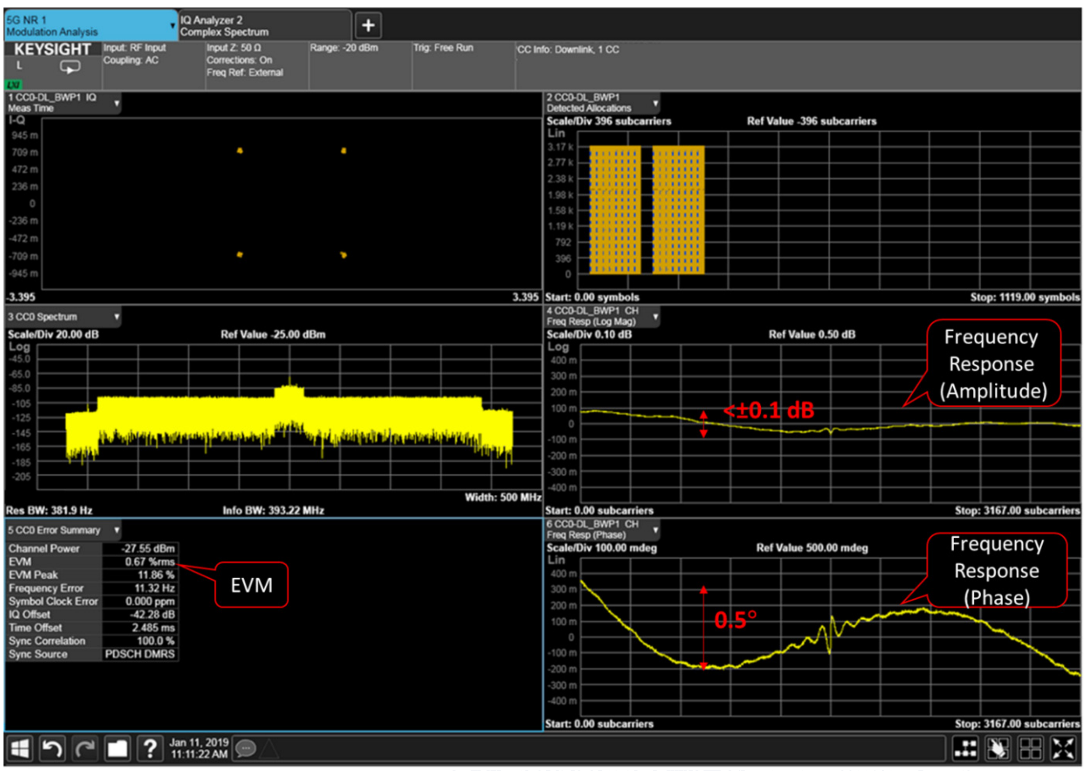

Figure 4: The frequency response of a 5G NR signal with 400 MHz bandwidth

Extend the Reference Plane to the DUT Plane

Calibration is critical to ensuring the measurement system produces accurate results. Cables, components, and switches in the paths between the instruments and the device under test (DUT) can degrade measurement accuracy because of flatness errors. You must extend the measurement accuracy from the signal generator's output (reference plane) to the DUT's test port as shown in Figure 5. Any network elements (cables, connectors, or fixtures) between the signal generator and the device will impact the signal's fidelity.

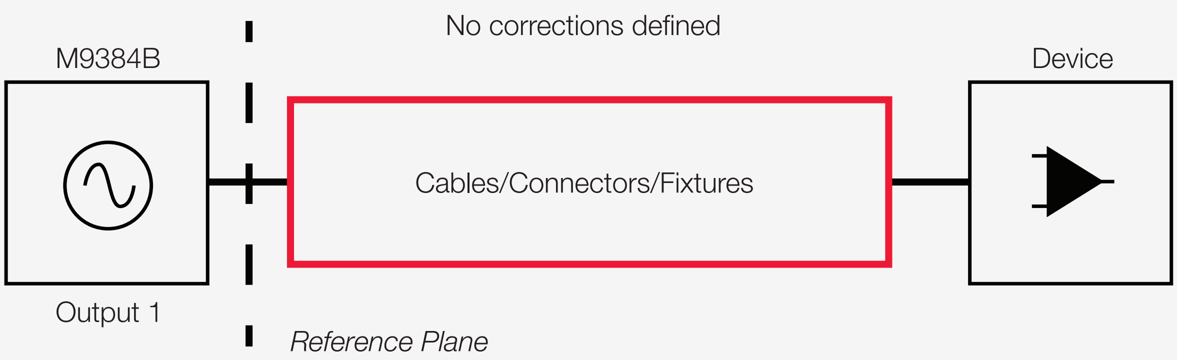

Figure 5: Network elements must be taken into consideration for channel correction

You can obtain a corrected filter by measuring the response of the network elements. Keysight provides a Measure Corrections Block Wizard which can guide you through the process of measuring and calculation corrections for an external network of cables, connectors, and other passive components connected between the signal generator and the DUT. Once you have characterized the desired topology, you can remove its effects from the output signal, moving the effective reference plane to the point at which the meter/analyzer was connected.

Tip #4: Improve the Out-of-Band Performance

Digital modulation that uses both amplitude and phase shifts generates distortion, also known as spectral regrowth. Figure 6 shows the spectral regrowth (red) of a digital modulation signal. The spectral regrowth spreads outside of the main channel. Adjacent Channel Power Ratio (ACPR) measurement is used to examine this type of distortion; it measures the ratio of the main channel power to the power that falls into adjacent channels. The ACPR measurement is a key transmitter characteristic in most cellular conformance specifications. To perform an ACPR measurement, you need a signal generator with ultra-low distortion performance to generate a specific standard-compliant test waveform.

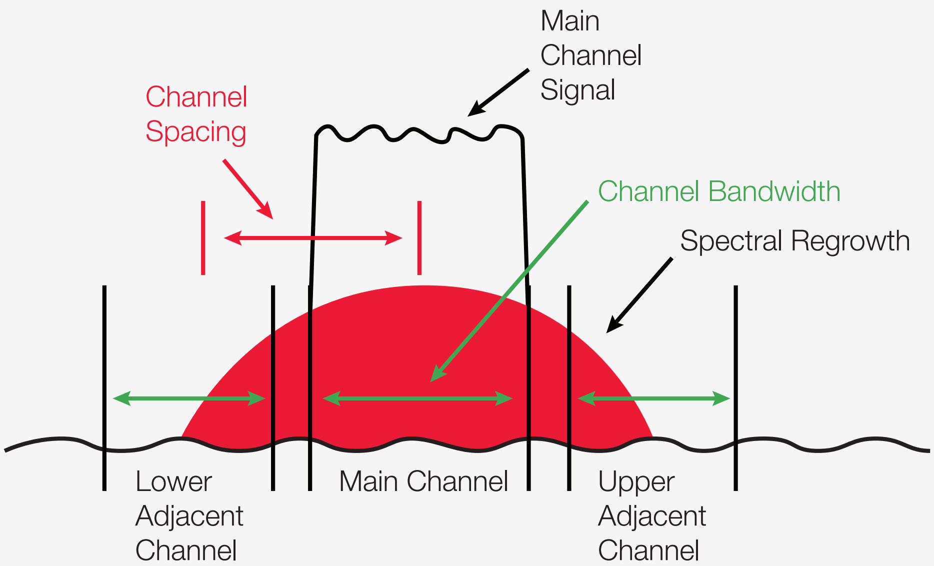

Figure 6: The spectral regrowth (red) of a digital modulation signal

The 3GPP 5G NR standard does not define a particular baseband filter for Orthogonal Frequency-Division Multiplexing (OFDM) signals. In practice, designers do implement OFDM windowing and baseband filtering to effectively minimize in-band and out-of-band emissions. For 5G RF component testing such as power amplifier, Keysight Signal Studio software offers options for baseband windowing and filtering that allow you to modify the error vector magnitude (EVM) and ACPR characteristics of the signal as shown in Figure 7.

As previously mentioned, a signal generator needs higher output power levels to compensate for excessive path loss at mmW frequencies. However, a high-power signal may result in a distorted signal, poor modulation quality (EVM) and spectrum regrowth (ACPR). It requires to optimize the signal generator's output linearity and minimize phase noise at high output levels, which provide the best EVM and ACPR performance for 5G NR tests.

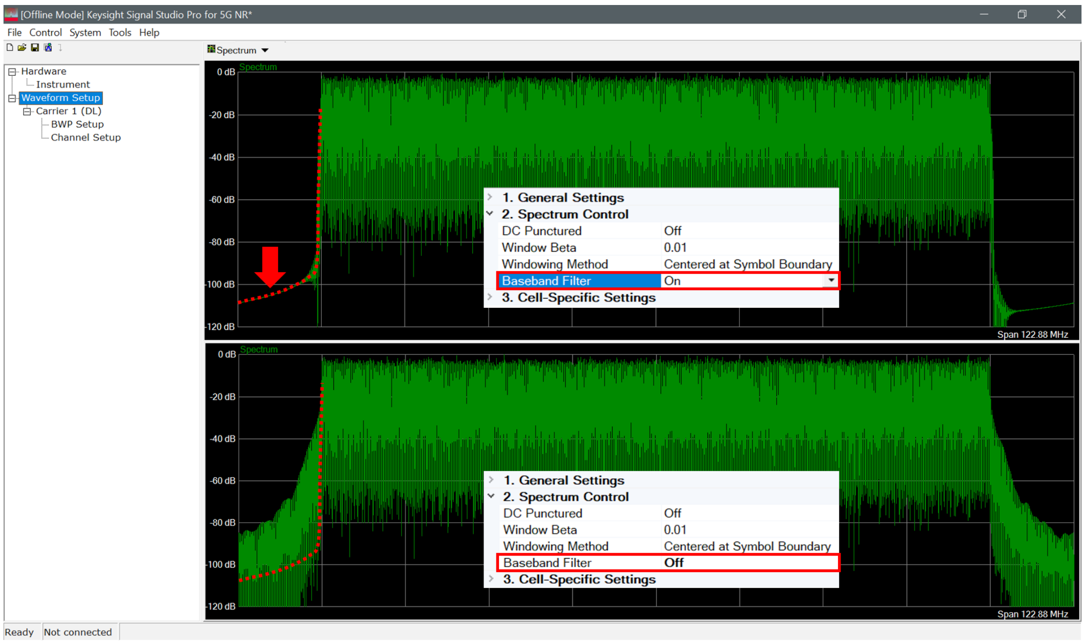

Figure 7: 5G NR signal spectrum simulation with and without a baseband filter

Keysight M9383B/M9384B VXG Microwave Signal Generator has a compact design that provides frequency coverage from 1 MHz to 44 GHz, up to 2 GHz RF modulation bandwidth, and dual coherent channels in a single instrument. The VXG microwave signal generators address the most demanding wideband millimeter wave applications, including 5G and satellite communications applications.

Working closely with other 5G industry leaders, Keysight has developed the VXG microwave signal generators to help deliver the next frontier of cellular technology, delivering the following benefits:

- Reduced test system setup complexity for 5G NR with the first dual-channel 44 GHz vector signal generator with 2 GHz RF modulation bandwidth in a single test instrument.
- Reduced OTA test system path loss thanks to the industry's highest output power versus error vector magnitude (EVM) and adjacent channel power ratio (ACPR) performance.
- Accelerated product development cycles through integration with PathWave Signal Generation, a software suite that providing access to a wide range of evolving standards-compliant 3GPP 5G NR signals for testing base stations, mobile terminal transmitters, and receivers with channel coding and multi-antenna support, including support for the very latest 3GPP Version 15.4.0 (2018-12) such as downlink Control Resource Set (COREST) updates, and downlink/uplink channel updates and configurations.

Conclusion

Generating a variety of standard-compliant 5G NR test signals requires a flexible waveform creation software platform and high performance hardware. The waveform creation software allows you to quickly and easily create custom 5G waveforms based on pre-configured, standard-based test signals. You should select a signal generator that meets your performance and bandwidth requirements, and is flexible enough to scale as 5G standards evolve.

Keysight's 5G waveform generation solution is 5G NR-ready and enables characterization of 5G NR devices and equipment from RF to mmWave frequencies with precision and modulation bandwidths up to 2 GHz.

Visit our 5G website to accelerate your 5G innovations.

Learn more at: www.keysight.com

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