Simulation Test Bench for NB-IoT Products

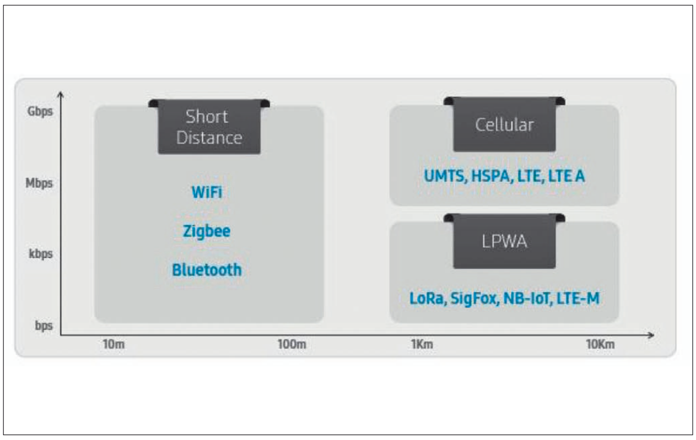

Figure 1: LPWA and cellular networks

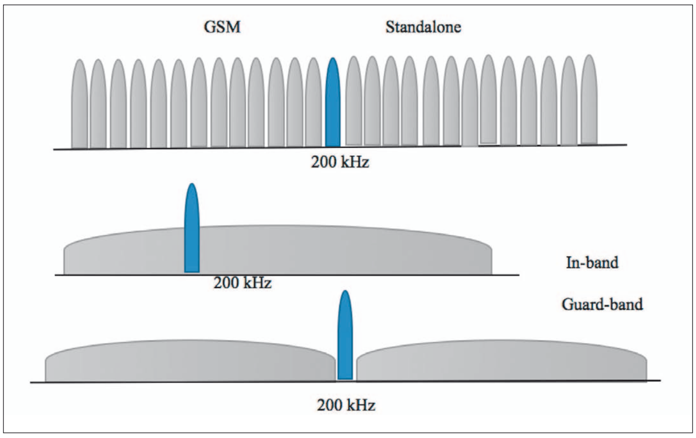

Figure 2: Deployment modes for NB-IoT

Over 26 billion devices, excluding smartphones, tablets, and computers could be connected to the IoT by 2020, requiring massive support from existing wireless networks.

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NI AWR software provides engineers with the RF simulation, automation, and access to knowledge (through online training videos and tutorials) to tackle these challenges from a methodical and low-risk approach.

Using a modular design approach, engineers can focus on combining all the relevant components in the RF signal path, including the supporting printed-circuit board (PCB) substrate and/or the device enclosure, into a hierarchical simulation network for analysis prior to manufacturing and test.

Integrated simulation technology and smart design automation are redefining the possibilities for companies at the forefront of IoT technology. To learn more about IoT trends and challenges, the companies developing the next generation of innovative IoT products, and the software enabling their success, visit ni.com/awr.

The MIoT

Among the mobile IoT (MIoT) technologies to be standardized by the 3rd Generation Partnership Project (3GPP), narrowband IoT (NB-IoT) represents the most promising low-power wide area network (LPWA) radio technology, enabling a wide range of devices and services to be connected using cellular telecommunications bands (Figure 1).

New capabilities in the NI AWR Design Environment platform, specifically Visual System Simulator (VSS) system design software, help designers meet the challenges in IoT device component design and simulation. Example VSS projects in this article include an LTE and NB-IoT uplink coexistence RX test bench, an NB-IoT uplink eNB RX test bench in the guard band of an LTE signal, and an in-band uplink eNB RX test bench.

Specifications	NB-IoT Requirement
Deployment	In-band & guard-band LTE, standalone
Coverage (maximum coupling loss)	164 dB
Downlink	OFDMA, 15 KHz tone spacing, TBCC, 1 Rx
Uplink	Single tone: 15 KHz and 3.75 KHz spacing, SC-FDMA: 15 KHz tone spacing, Turbocode
Bandwidth	180 KHz
Highest modulation	QPSK
Link peak rate (DL/UL)	DL: ~30 kbps UL: ~60 kbps
Duplexing	HD FDD
Duty cycle	Up to 100%, no channel access restrictions
MTU	Max. PDCP SDU size 1600 B
Power saving	PSM, extended Idle mode DRX with up to 3 h cycle, Connected mode DRX with up to 10.24 s cycle
UE Power class	23 dBm or 20 dBm

Table 1 shows that the design criteria for existing cellular technology and IoT are quite different

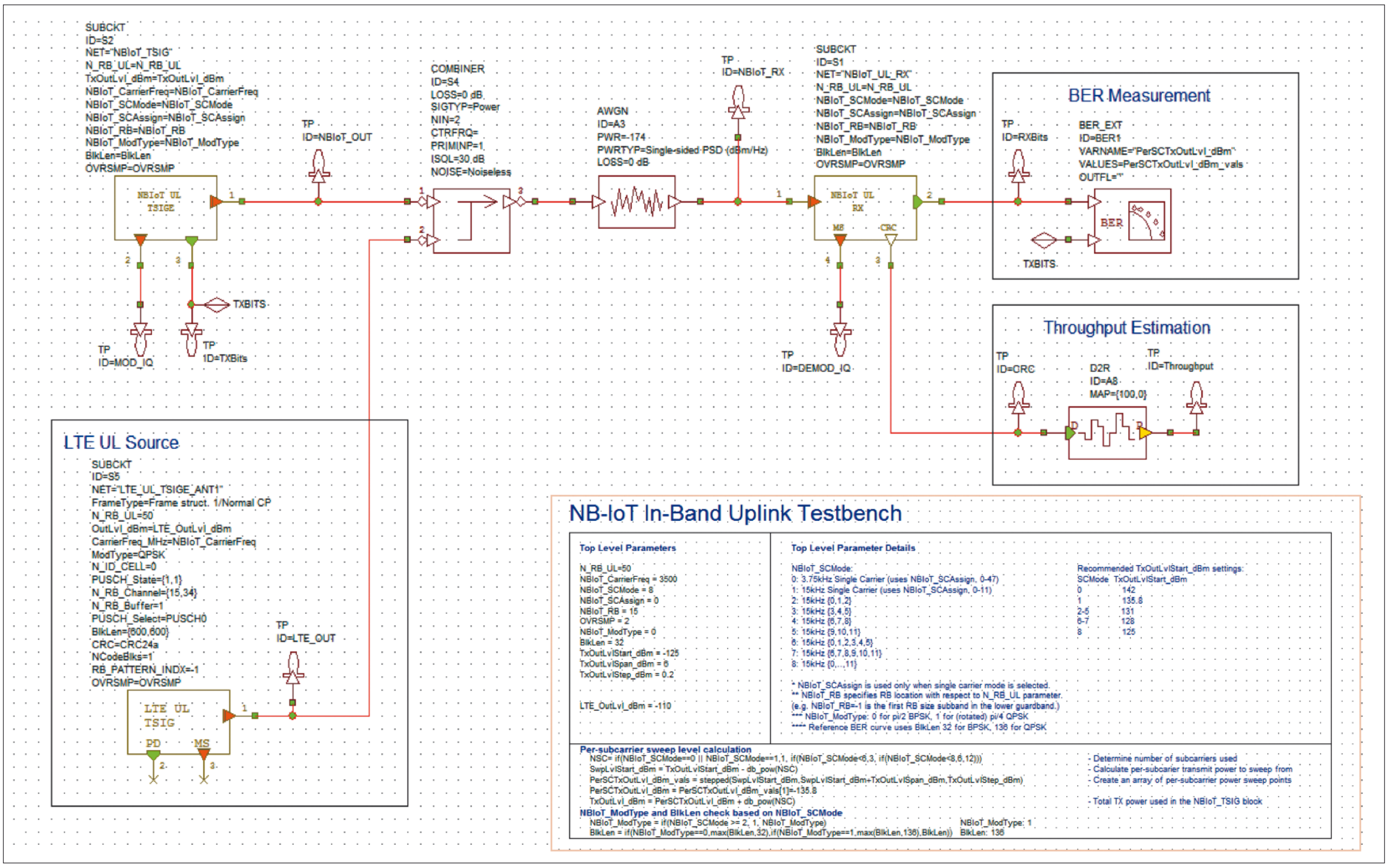

Figure 3: NB-IoT in-band uplink test bench in VSS

System Requirements

In Release-13, the 3GPP specified a new radio air interface for MIoT applications that focuses specifically on improved indoor coverage, low-cost devices (less than $5 per module), long battery lifetime (more than 10 years), massive connectivity (supporting a large number of connected devices, around 50,000 per cell), and low latency (less than 10 msec).

NB-IoT will enable operators to expand wireless capabilities to evolving businesses such as smart metering and tracking and will open more industry opportunities, such as Smart City and eHealth infrastructure. NB-IoT will efficiently connect these many devices using already established mobile networks and will handle small amounts of fairly infrequent twoway data securely and reliably.

The standard utilizes a 180 kHz UE RF bandwidth for both downlink and uplink, enabling three different deployment modes, as shown in Figure 2.

These modes include:

Standalone operation, in which a global system for mobile communications (GSM) operator can replace a GSM carrier (200 kHz) with NB-IoT,

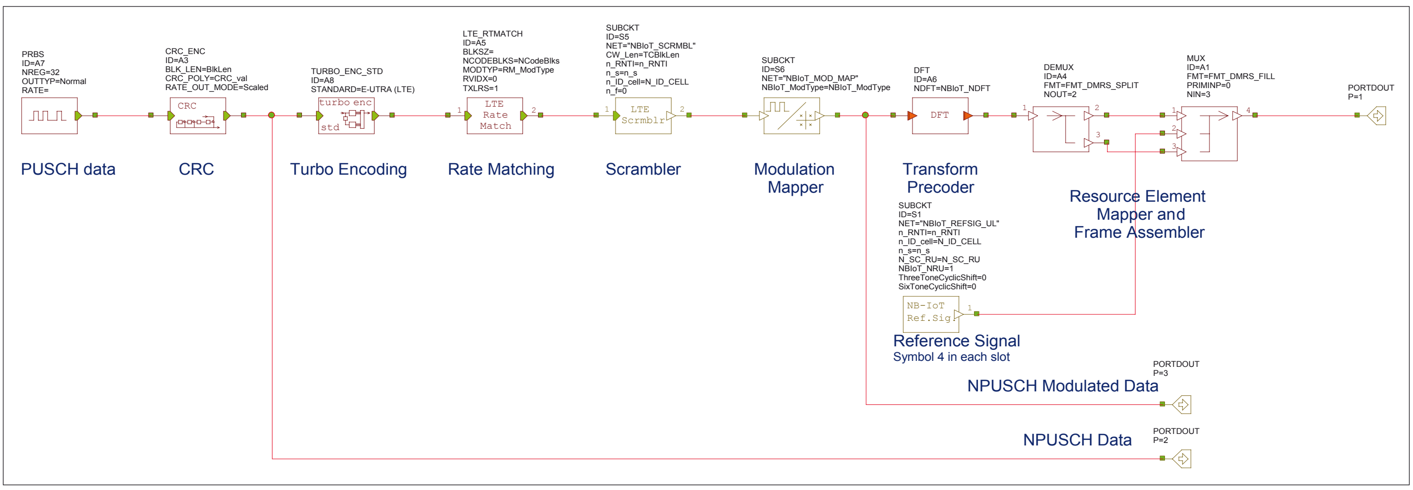

Figure 4: PUSCH encoder in VSS

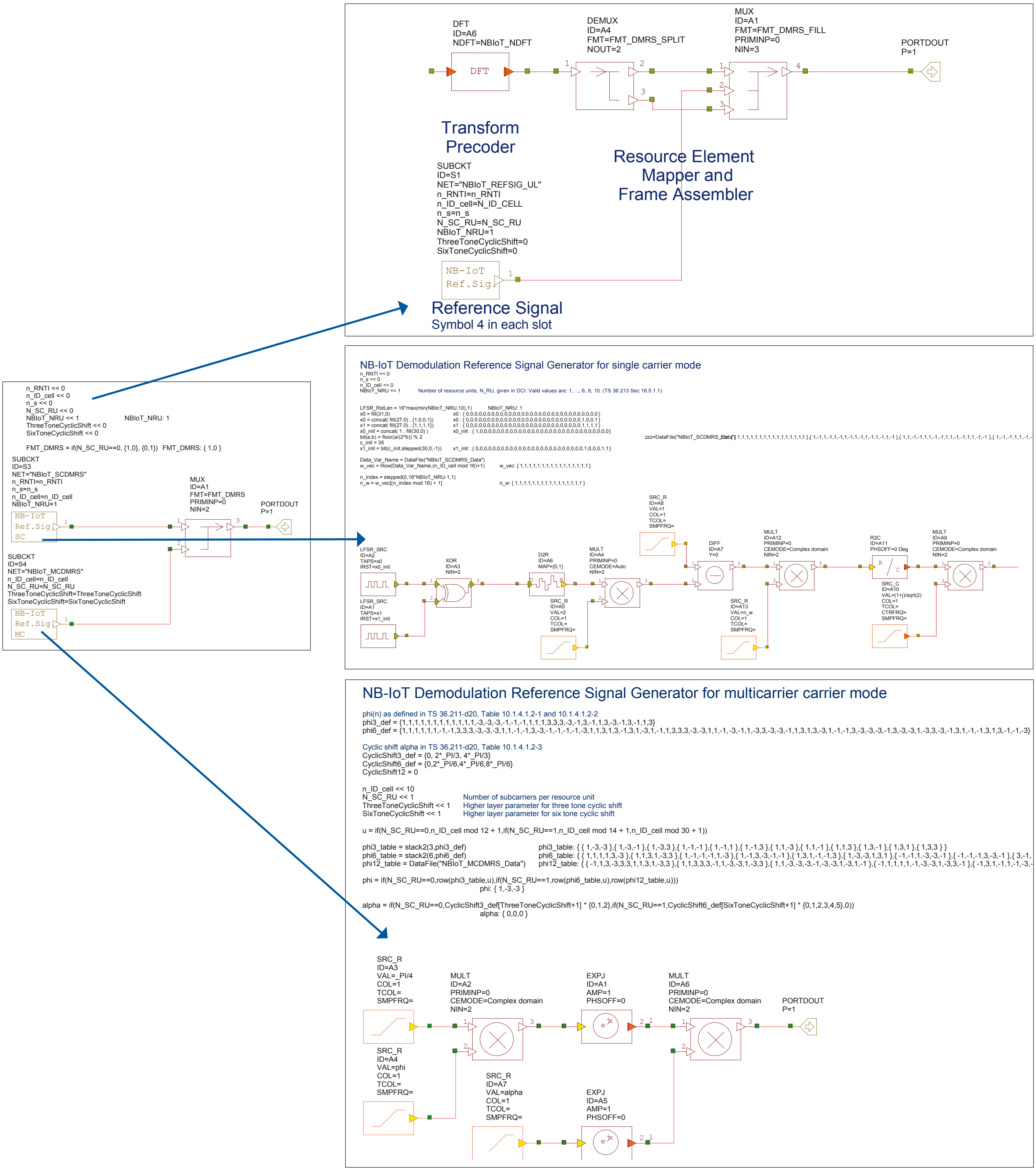

Figure 5: Transform precoding, resource element mapping, and frame assembly

re-farming dedicated spectrum to, for instance, GSM EDGE radio access network (GERAN) systems. This is possible because both the GSM carrier's bandwidth and the NB-IoT bandwidth, inclusive of guard band, are 200 kHz.

Guard-band deployment utilizing the unused resource blocks within an LTE carrier's guard band.

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LTE operators can also deploy NB-IoT inside an LTE carrier by allocating one of the 180-kHz physical resource blocks (PRBs) to NB-IoT. The NB-IoT air interface is optimized to ensure harmonious coexistence with LTE without compromising the performance of either.

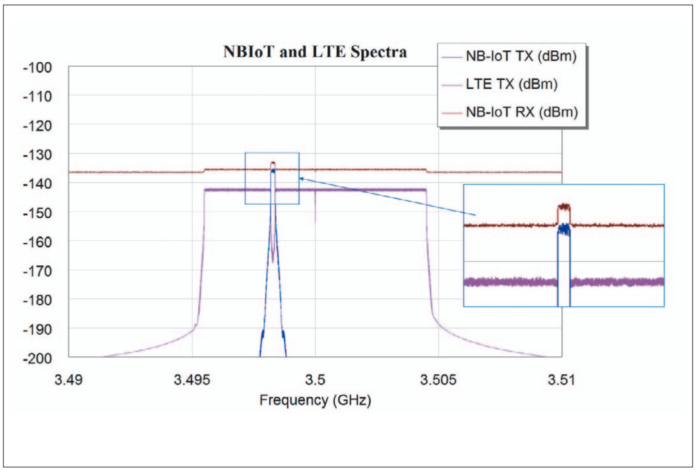

Figure 6: NB-IoT/LTE spectra for in-band mode

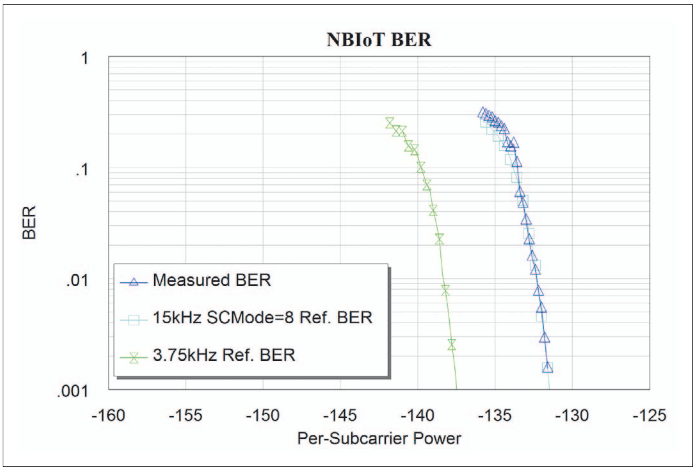

Figure 7: NB-IoT BER

Whereas wireless cellular technologies require large bandwidth with high data rates and low latency at the expense of lower device battery lifetime, the criteria for IoT requires robust data transmission with significantly lower data rates, long range coverage, and long device battery lifetime. While LTE uses bandwidth greater than 1.4 MHz, IoT communication can suffice with kHz range bandwidths. As a result, the use of existing GSM and LTE technologies for IoT communication wastes spectrum and data rate. Also, the introduction of a narrowband channel such as single tone 3.75 kHz quadruples the number of connections in the LTE traditional 15 kHz subcarrier spacing.

Device cost is another factor differentiating mobile devices designed for mobile voice, messaging, and high-speed data transmission compared to NB-IoT applications that simply require low speed but reliable data transfer. Many NB-IoT use cases require a low device price to address very practical considerations such as ease of installation or risk of theft.

Developing robust, low-cost, and power-efficient IoT devices that support low data rates and large area coverage represents a departure from component design efforts that have been driven by very different system requirements. RF system simulation will provide insight into these new challenges as well as the design support and analysis of UE modules, antennas, RF front ends, and wireless networks communicating with co-existing NB-IoT/LTE signals.

NB-IoT will heavily utilize LTE technology to support new development, including downlink orthogonal frequency-division multiple-access (OFDMA), uplink single-carrier frequency-division multiple-access (SC-FDMA), channel coding, rate matching, interleaving, and more. This significantly reduces the time required to develop full specifications, as well as the time required for developing NB-IoT products by new and existing LTE equipment and software vendors.

NB-IoT In-Band Uplink eNB RX Test Bench

The VSS project (top-level) shown in Figure 3 demonstrates operation of an NB-IoT system inside an LTE signal band. The NB-IoT uplink signal is configured as in band, NPUSCH format 1, compliant with the 3GPP Release 13 specification. In this example, the NB-IoT signal is placed in an unused RB within the LTE band. The simulation of NB-IoT and LTE coexistence in different operating scenarios supports companies engaged in 3GPP standardization and product development. The available NB-IoT examples in VSS enable engineers to study in-band and guard-band operation modes.

The NB-IoT uplink supports both multi-tone and single-tone transmissions. Multi-tone transmission is based on SC-FDMA, with the same 15 kHz subcarrier spacing, 0.5 ms slot, and 1 ms subframe as LTE. SC-FDMA is an attractive alternative to OFDMA, especially in uplink communications where lower peak-to-average power

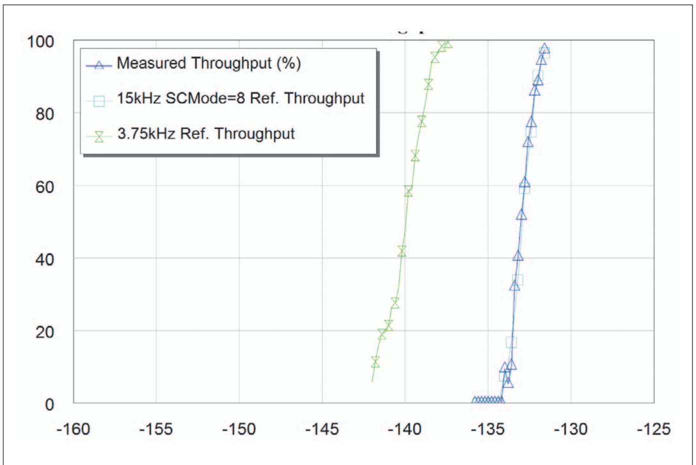

Figure 8: Simulated throughput for in-band NB-IoT

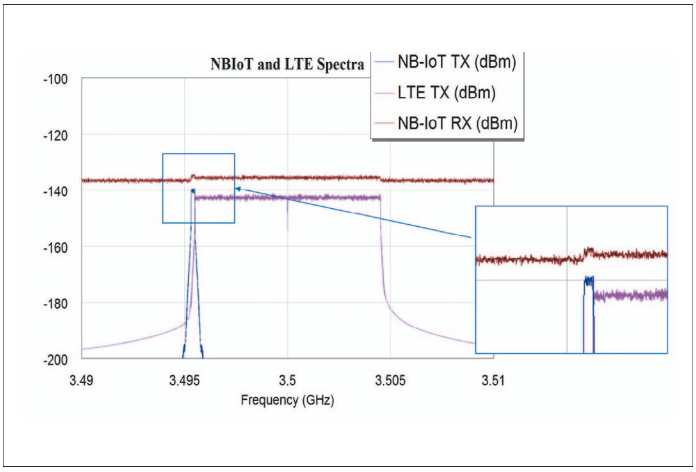

Figure 9: NB-IoT/LTE spectra for guard-band mode

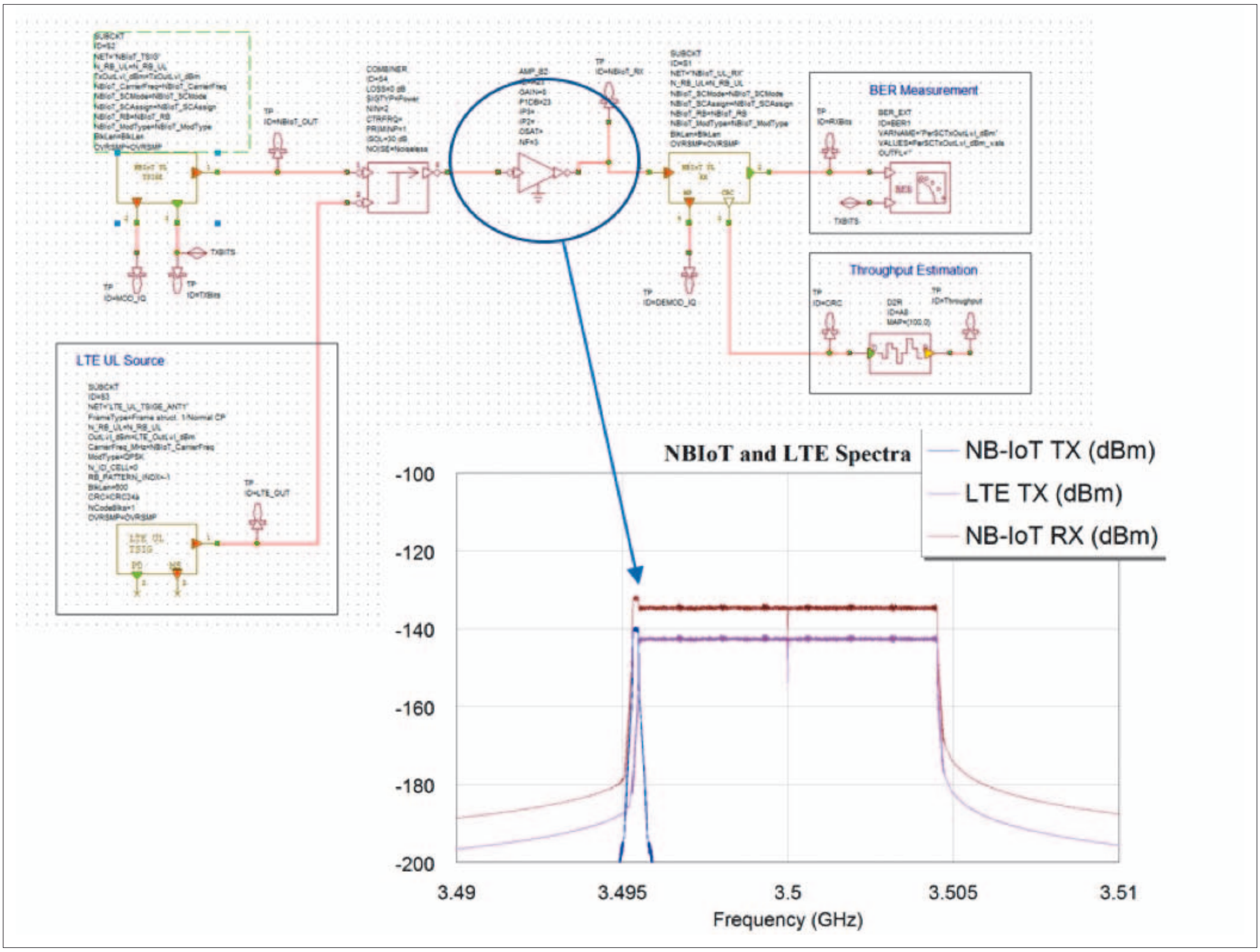

Figure 10: NB-IoT/LTE spectra with amplifier DUT

ratio (PAPR) greatly benefits the mobile terminal in terms of transmit power efficiency, which extends battery life and reduces the cost of the power amplifier.

Single-tone transmission supports two subcarrier spacing options: 15 kHz and 3.75 kHz. The additional 3.75 kHz option uses a 2 ms slot and provides stronger coverage to reach challenging locations, such as deep inside buildings, where signal strength can be limited. The 15 kHz numerology is identical to LTE and, as a result, achieves excellent coexistence performance.

The data subcarriers are modulated using ?/2 binary phase-shift keying (BPSK) and ?/4 quadrature phase-shift keying (QPSK) with phase continuity between symbols, which reduces peak-to-average power ratio (PAPR) and allows power amplifiers to operate in more efficient (saturated) regions. Selection of the number of 15 kHz subcarriers for a resource unit can be set to 1, 3, 6, or 12, supporting both single-tone and multi-tone transmission of the uplink NB-IoT carrier with a total system bandwidth of 180 kHz (up to 12 15-kHz subcarriers or 48 3.75-kHz subcarriers).

The NB-IoT uplink physical channel includes a narrowband physical random-access channel (NPRACH) and narrowband physical uplink shared channel (NPUSCH). The NPRACH is a new channel designed to accommodate the NB-IoT 180 kHz uplink bandwidth, since the legacy LTE PRACH requires a 1.08 MHz bandwidth. Random access provides initial access when establishing a radio link and scheduling request and is responsible for achieving uplink synchronization, which is important for maintaining uplink orthogonality in NB-IoT.

The NPUSCH supports two formats. Format 1 is used for carrying uplink data, supports multi-tone transmission and uses the same LTE turbo code for error correction. The maximum transport block size of NPUSCH Format 1 is 1000 bits, which is much lower than that in LTE. Format 2 is used for signaling hybrid automatic repeat request (HARQ) acknowledgement for NPDSCH and uses a repetition code for error correction. In this case, the UE can be allocated with 12, 6, or 3 tones. The 6-tone and 3-tone formats are introduced for NB-IoT UEs that, due to coverage limitations, cannot benefit from the higher UE bandwidth allocation.

NPUSCH encoding in the VSS example project is shown in Figure 4. This sub-block generates a pseudo-random binary sequence, which undergoes cyclic redundancy check (CRC) followed by turbo encoding and rate matching for uplink LTE transmissions that performs sub-block interleaving on the bit stream out of the encoders. For each code word, all the bits transmitted on the physical uplink shared channel in one sub-frame are then scrambled with a UE-specific scrambling sequence prior to the modulation mapping, which has been selected by the system developer through the configuration options.

SC-FDMA can be interpreted as a linearly pre-coded OFDMA scheme, in the sense that it has an additional discrete Fourier transform (DFT) processing step preceding the conventional OFDMA processing. In the example in Figure 5, a DFT is performed (transform pre-coder) before the NPUSCH channel is multiplexed with the reference signal subcarriers (either single or multi-tone) by first mapping them to the appropriate physical resources and then to the OFDM symbols and slots within each frame.

Much like OFDMA, SC-FDMA divides the transmission bandwidth into multiple parallel sub- carriers, maintaining the orthogonality of the subcarriers by the addition of the cyclic prefix (CP) as a guard interval. However, in SC-FDMA the data symbols are not directly assigned to each subcarrier independently as in OFDMA. Instead, the signal that is assigned to each subcarrier is a linear combination of all modulated data symbols transmitted at the same time instant. The difference between SC-FDMA transmission and OFDMA transmission is an additional DFT block (Figure 5) before the subcarrier mapping.

A similar set of blocks are used to generate the LTE signal, which is then combined with the NB-IoT waveform, passed through an additive white Gaussian noise (AWGN) channel and terminated in an NB-IoT UL receiver that is responsible for demodulation and decoding of the PUSCH signal. For component and/or system designers, the AWGN channel model can be replaced with a different channel model or device under test (DUT).

The test bench in this VSS example has been configured to monitor the TX signal spectrum at various points in the link (Figure 6), as well as NB-IoT link performance in the presence of LTE UL signal, IQ constellation of the transmitted and demodulated signals, bit error rate (BER), block error rate (BLER), and throughput (Figures 7 and 8), and CRC error for each block.

A related example demonstrates operation of NB-IoT in the guard band of an LTE signal. The project is essentially the same as in the previous example with a simple change to the NB-IoT resource block location. For guard-band operation, NBIoT_RB is set to <0 or >N_RB_UL (upper limit) in order to operate in the lower or upper guard band, respectively. In-band operation is obtained by setting the NB-IoT resource block at any value between these limits. The spectra for an NB_IoT/LTE UL operating in guard-band mode is shown in Figure 9.

As previously mentioned, a front-end module, power amplifier, and/or antenna design can be added to or substituted for the current AWGN channel model, which serves as a placeholder for a DUT. Figure 10 shows an amplifier design in Microwave Office circuit design software with P1dB = 20 dBm inserted between the UL transmitter and receiver. Designers are then able to sweep any number of control parameters such as input power or toggle the different NB-IoT sub-carrier modulation schemes to investigate impact on performance such as error vector magnitude (EVM). ◄