AWR SOFTWARE

Internet of Things (IoT)

CONTENTS

Introduction

The wide range of internet of things (IoT) applications in development today are made possible by smart devices operating across different network configurations, frequencies, power requirements, and protocols. Developing cost-effective IoT solutions requires a smart, organized approach to radio and antenna integration within a design flow that may have little to do with traditional RF product development. Many IoT designers are utilizing off-the-shelf, pre-certified modules to circumvent some of the technical challenges such as RF integration and emission compliance, as well as development costs associated with such a wide range of devices and networks. Even with this modular approach, integrating a transceiver modem, RF front-end components, and antenna(s) within a size-restricted enclosure is a sensitive design effort that is increasingly being tackled by engineers with little or no RF design experience.

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 awr.com.

Simulation Test Bench for NB-IoT Products

Overview

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

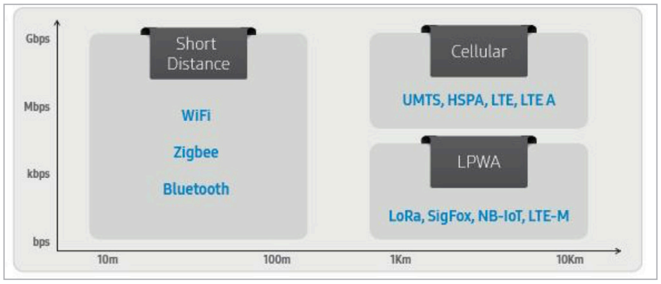

Figure 1: LPWA and cellular networks.

New capabilities in the 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.

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.

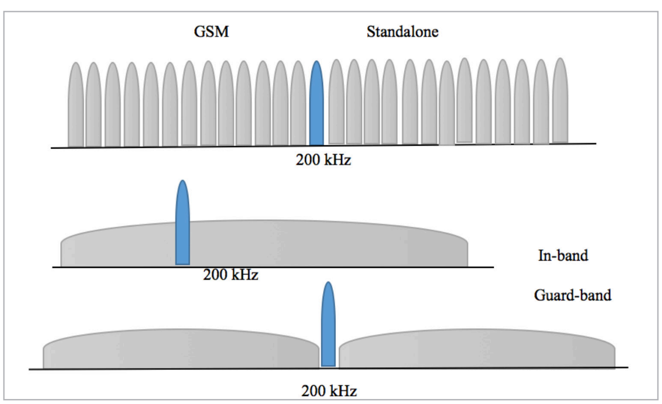

Figure 2: Deployment modes for NB-IoT.

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, 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.

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

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

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.

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.

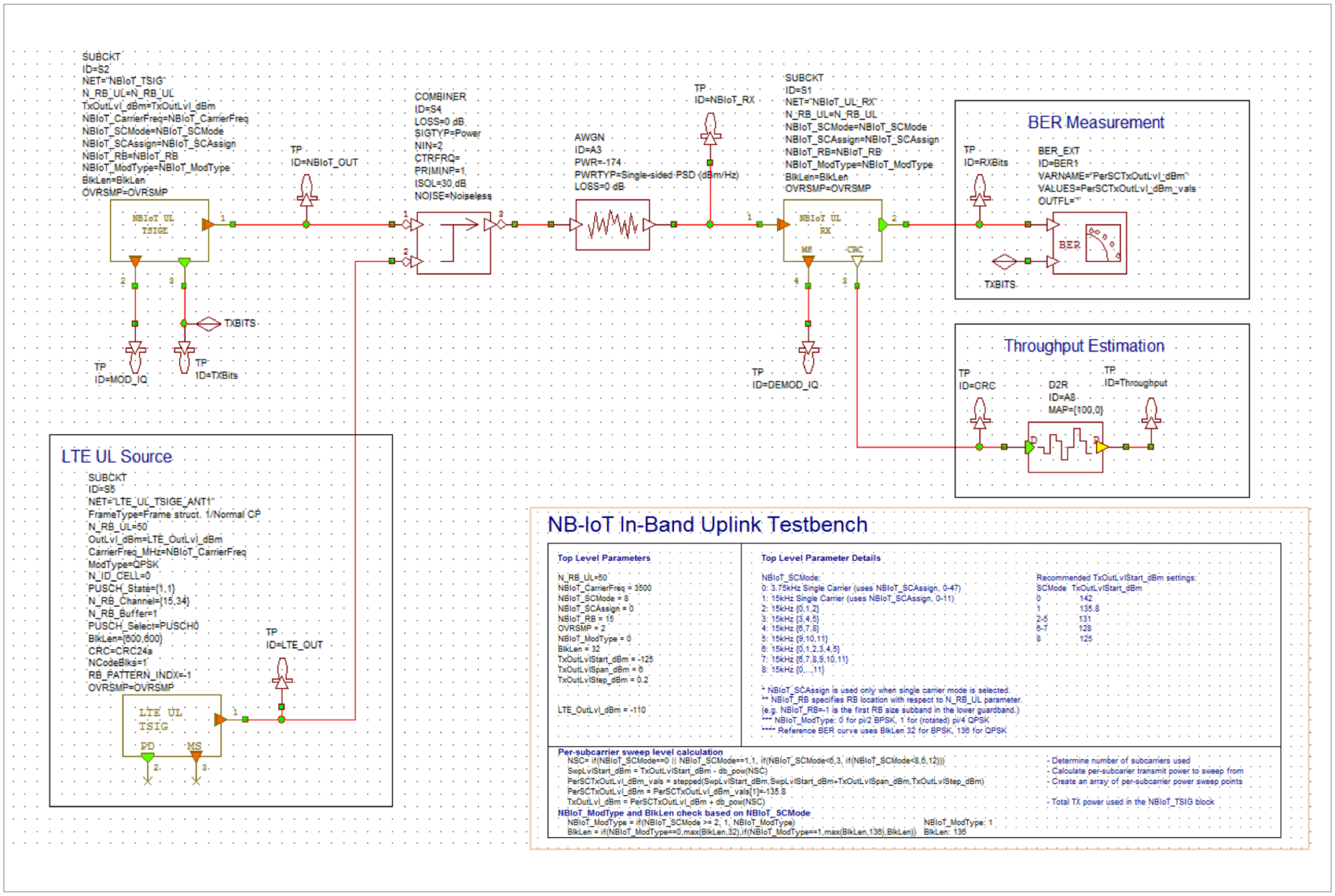

Figure 3: NB-IoT in-band uplink test bench in VSS.

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 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 π/2 binary phase-shift keying (BPSK) and π/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.

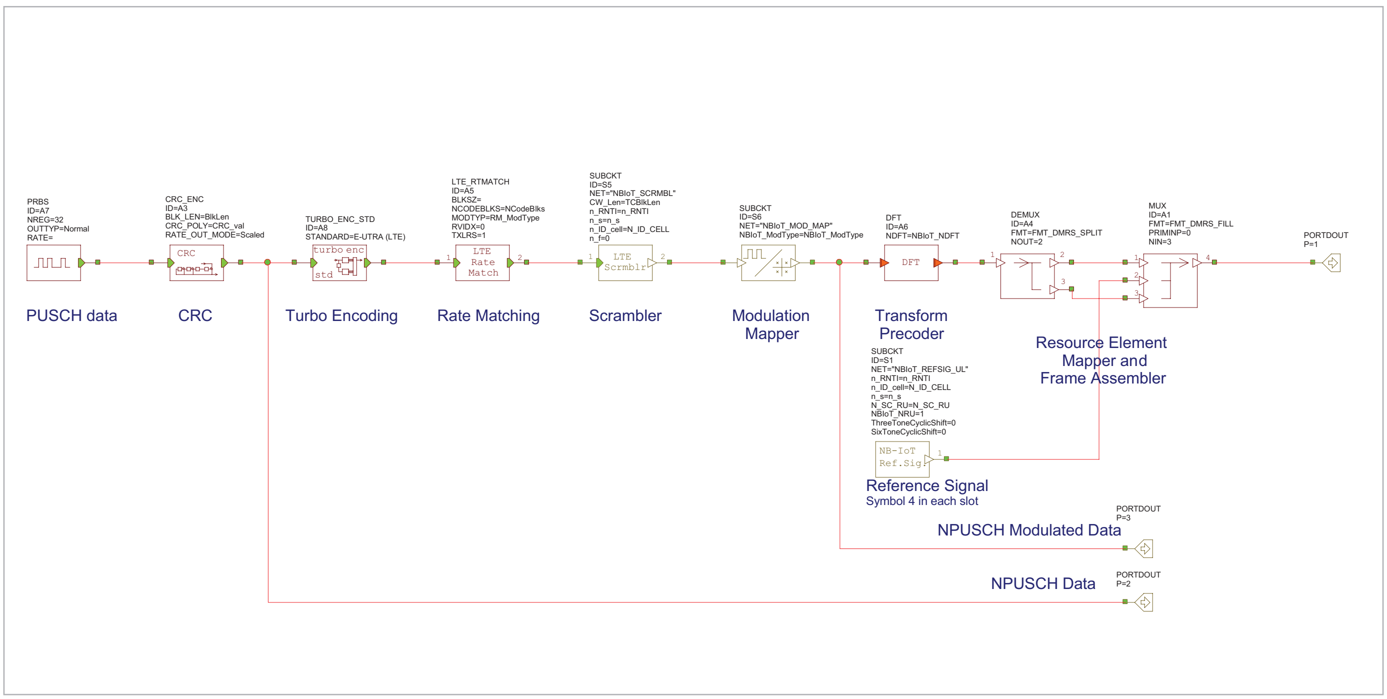

Figure 4: PUSCH encoder in VSS.

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 (next page), 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.

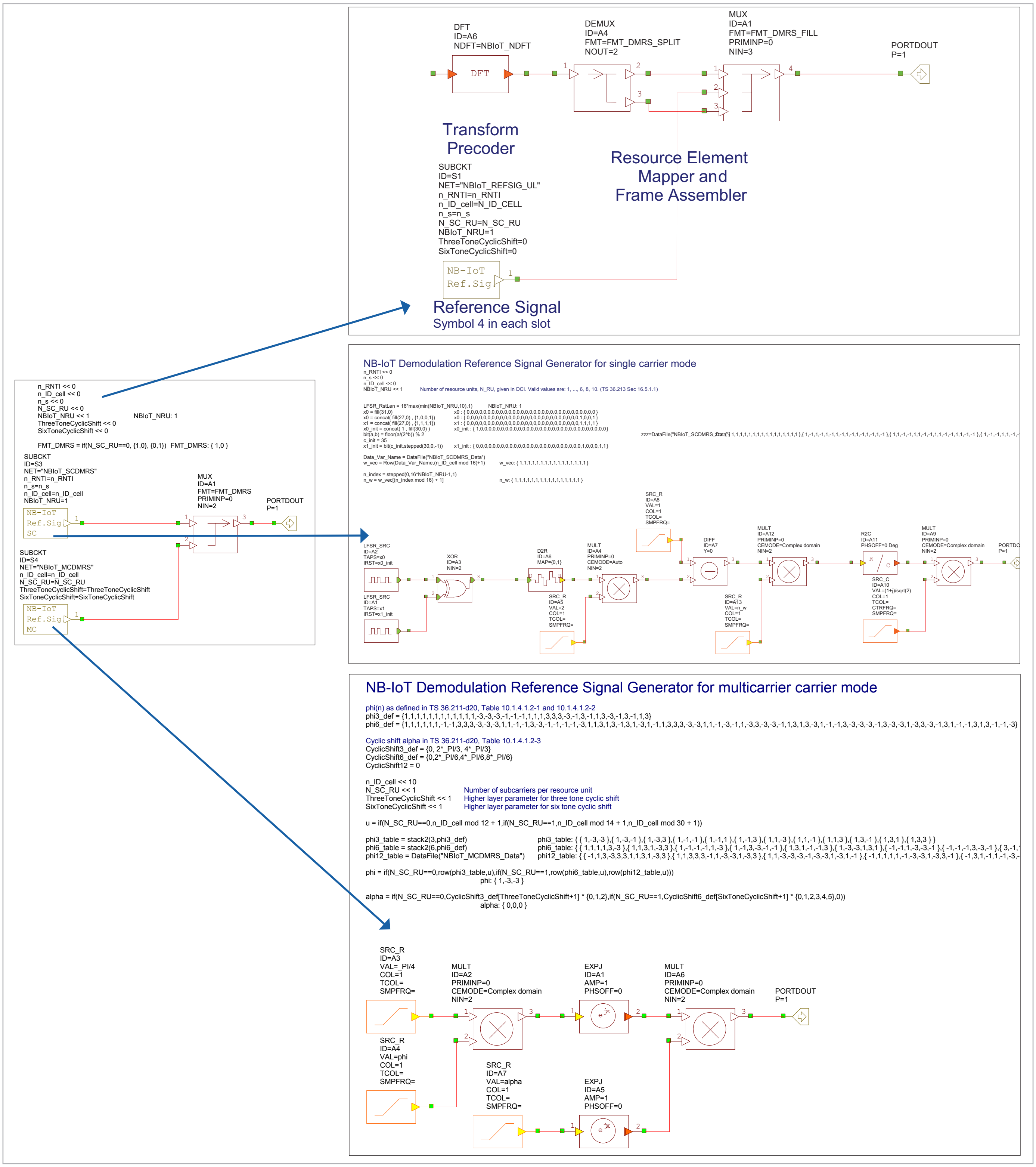

Figure 5: Transform precoding, resource element mapping, and frame assembly.

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.

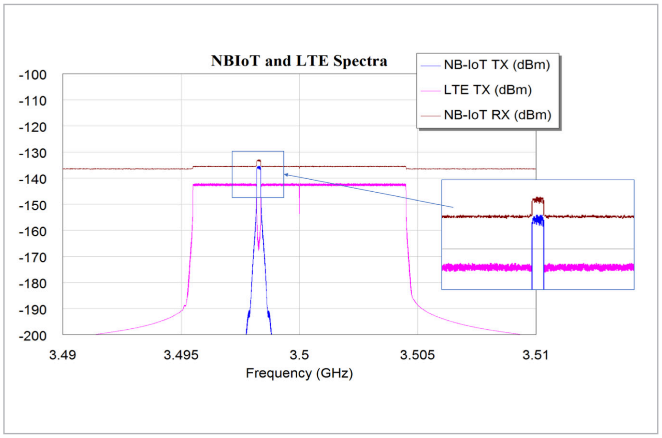

Figure 6: NB-IoT/LTE spectra for in-band mode.

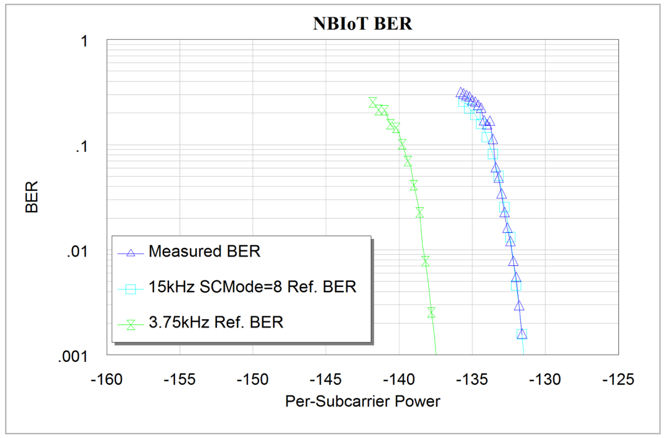

Figure 7: NB-IoT BER.

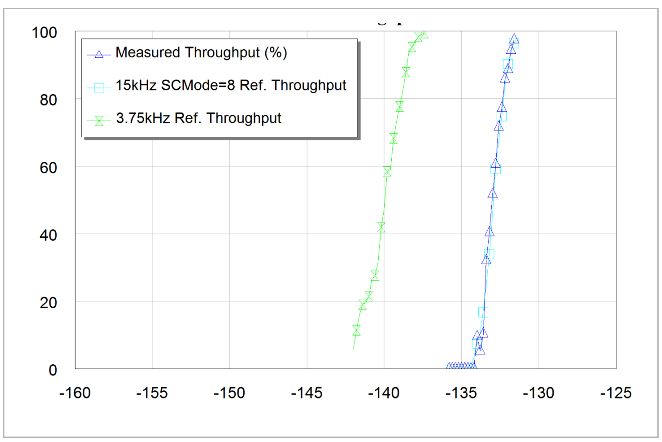

Figure 8: Simulated throughput for in-band NB-IoT.

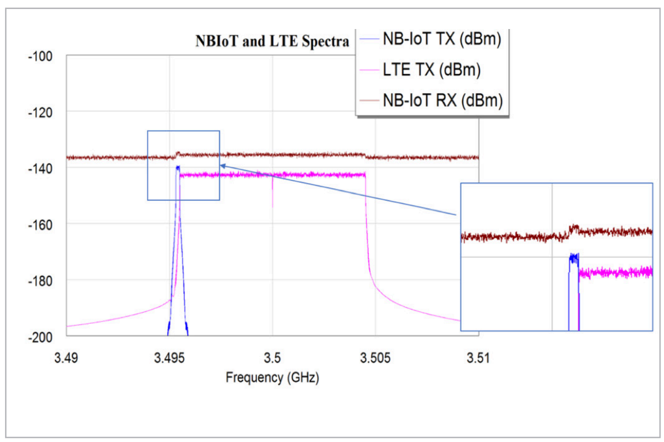

Figure 9: NB-IoT/LTE spectra for guard-band mode.

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 (π/2 BPSK or π /4 QPSK) to investigate impact on performance such as error vector magnitude (EVM).

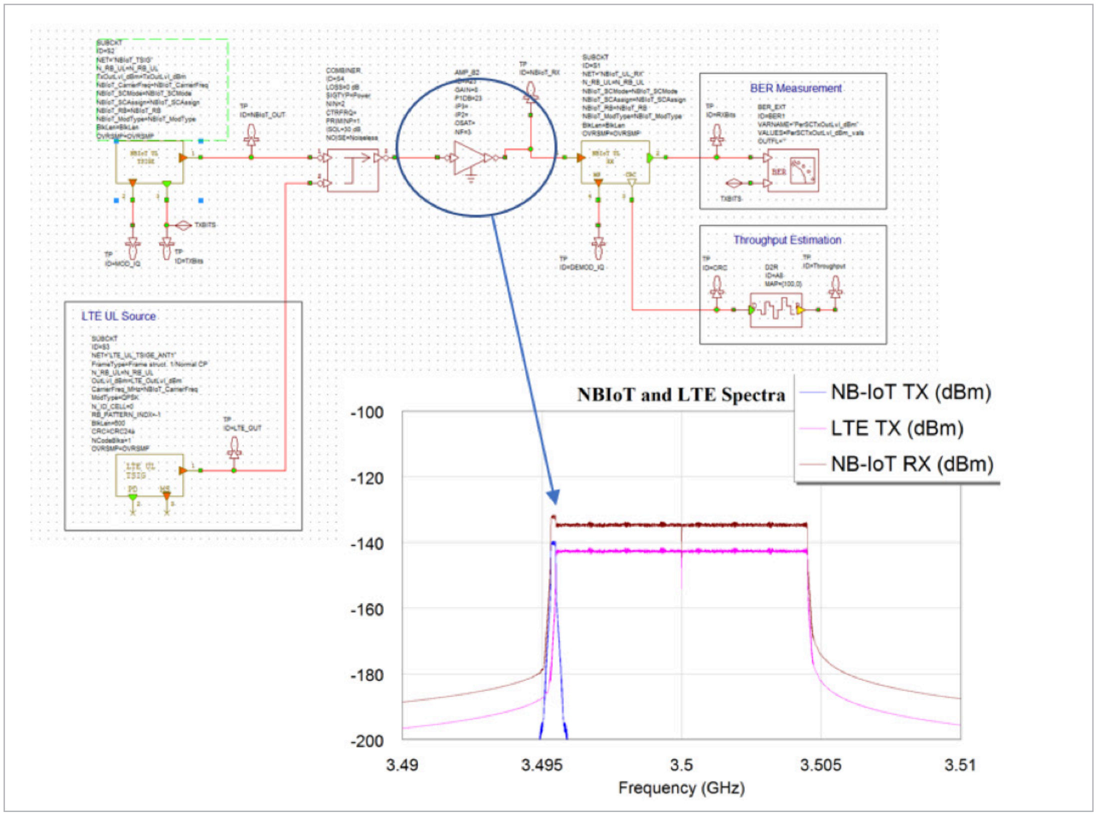

Figure 10: NB-IoT/LTE spectra with amplifier DUT.

Conclusion

NB-IoT leverages existing LTE wireless networks to support a large future ecosystem of low-cost mobile IoT devices. While the use of the existing LTE infrastructure and relaxed performance requirements due to low data rates will help offset some design challenges, requirements such as the need for low cost, increased coverage area, and longer battery life with sustained reachability pose difficult design challenges. VSS provides for NB-IoT system development and offers test benches for simulating virtual pre-silicon components, thereby saving designers valuable time and effort in bringing new products to market.

Synthesizing MIMO Antennas for Compact Devices

Overview

Upcoming IoT devices will rely heavily on customized antenna solutions optimized for performance, cost, and size. Multiple-in-multiple-out (MIMO) is a technique that uses multiple antennas on a single device, thus providing greater throughput and performance reliability for wireless devices, however, this requires not only good antennas, but also high isolation between them. This can be achieved by separating the antennas but doing so can make the device quite large and/or require external antennas. High isolation can also be achieved between closely-spaced internal antennas by using chokes, matching networks, and other techniques, each having their own advantages and drawbacks.

Optimizing antennas by hand to meet multiple performance metrics such as impedance matching, coupling, radiation efficiency, and operating bandwidth is a time-consuming process involving numerous iterative simulations and a significant amount of design knowledge. This application note presents an alternative method using AWR software's AntSyn™ antenna synthesis tool, which enables designers to synthesize compact MIMO antenna arrays automatically from user requirements, saving significant design time and allowing even inexperienced designers to design antennas that successfully meet size, cost, and performance requirements.

Antenna Design by Requirements

AntSyn software combines advanced optimization algorithms, expert systems, and electromagnetic (EM) simulation into a user-friendly tool that operates on a "what you want is what you get" principle, where the user inputs the antenna requirements rather than a (parameterized) physical design. For this application, the specifications are items like frequency band, target impedance match (return loss), size/form factor, and coupling. These requirements are input into the intuitive "spec sheet" user interface, which is automatically organized into a project file. A partial spec sheet, showing a sample of the relevant specifications for MIMO, is shown in Figure 1.

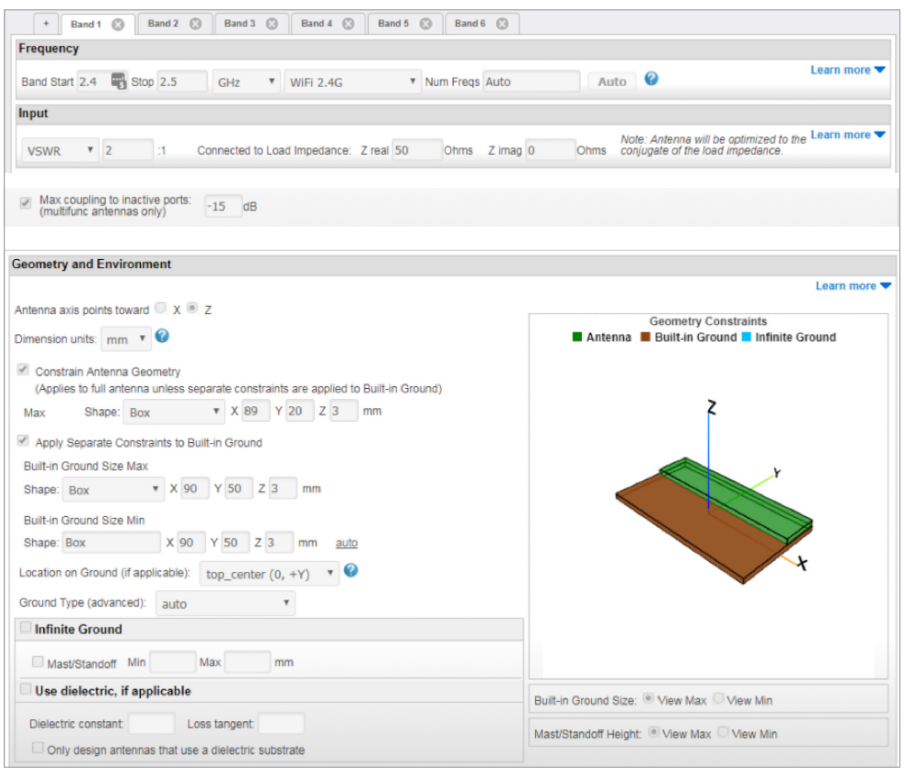

Figure 1: AntSyn spec sheet for MIMO.

By running the spec sheet, AntSyn software returns one or more optimized antenna designs, the results of which are viewed using a customizable dashboard for rapid evaluation, as shown in Figure 2.

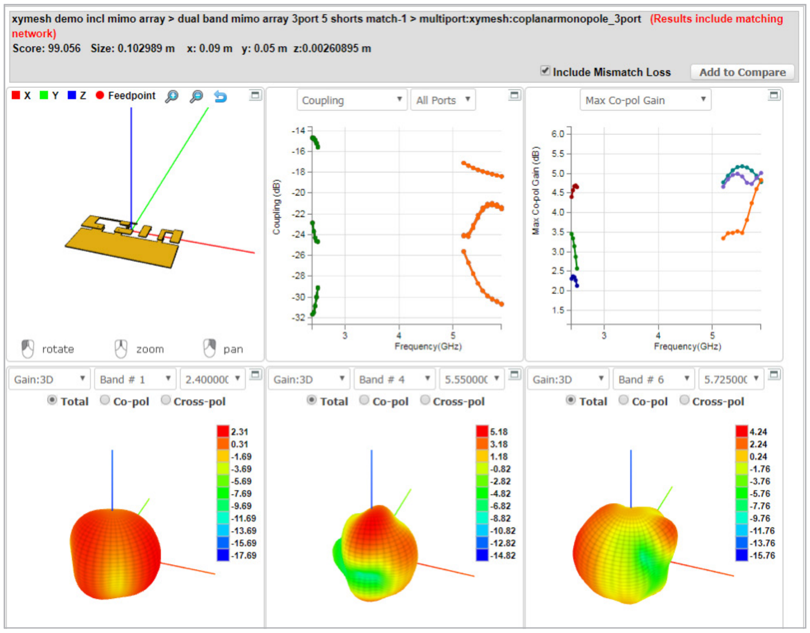

Figure 2: AntSyn software returns one or more optimized antenna designs.

The user-specified dashboard can be set to view the proposed 3D model, input impedance (match) versus frequency in several formats, maximum gain versus frequency, radiation pattern cuts, and qualitative star rating, all of which help identify good performers quickly. AntSyn software has been used to develop a wide range of antenna types such as single band, dual band, multiband, broadband/ ultra-wideband (>100:1), high efficiency, loaded, electrically small, phased array, wire, patch, conformal, handset, horn, dual-polarized, and multifunction.

AntSyn software offers over 29 antennas and provides features that are made specifically to generate compact MIMO designs, including new multi-function computer-generated mesh antennas with multiple ports, augmented matching network optimization that allows each port to be separately matched and optimized, and improved accuracy and features for ground planes.

The new mesh antennas are particularly unique and flexible. They are a set of four new antenna types, with either two or three ports (more ports to be supported in the future). These ports can be independently assigned to different bands, which can have very diverse RF requirements such as different polarization, gain patterns, and frequencies. The antenna mesh is optimized by AntSyn software for the specifications given and it is sufficiently flexible to enable the software to essentially invent new antennas.

Images of these antennas are shown in Figure 3. The two standard versions of the mesh antenna can be placed on any corner or edge on the ground, or they can be placed in the center as shown. The ground can be solid beneath these antennas or it can be an optimized mesh as well. The coplanar monopole version does not have a ground beneath the mesh but is expected to project over one edge of the ground, which can be useful in many device applications.

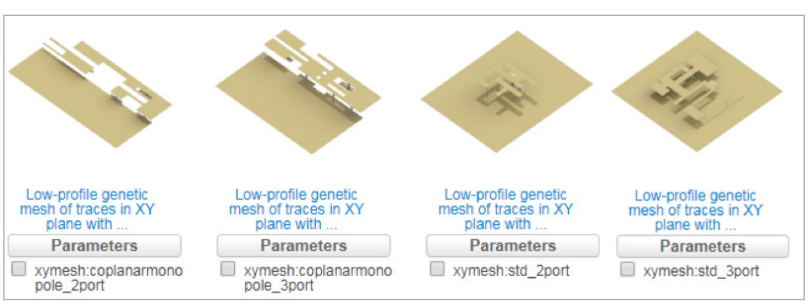

Figure 3: Sample mesh antennas.

The following examples use the coplanar monopole, which is known to have excellent bandwidth and flexibility for this application. The examples demonstrate how AntSyn software is able to use these antennas to synthesize high-performance MIMO arrays with good isolation and impedance matches.

Examples

The AntSyn tool was used to create both a two-port and a three-port MIMO antenna on a notional compact device using the new features in its latest release.

This notional device had the following characteristics and requirements:

- Dual-band Wi-Fi
- 2.4 and 5 GHz bands
- IoT device package
- Compact, planar geometry
- Approximate size of a standard business card, 90 mm x 50 mm
- Antenna integrated with electronics
- Antennas placed along long edge
- MIMO
- Two or three ports/antennas for transmit and receive on each device
- Maximized isolation between ports to create de-coupled channels

First, a two-port MIMO antenna using the multi-function mesh coplanar monopole type was optimized using AntSyn software. The specifications shown in Figure 1 were used to define the desired performance of the MIMO antenna in this example (note with the exception that a matching network was not used). This particular antenna used air as its dielectric. The resulting antenna and its predicted performance is shown in Figure 4.
This antenna has reasonably good voltage standing wave ratio (VSWR) and isolation performance for the dual-band Wi-Fi frequencies for

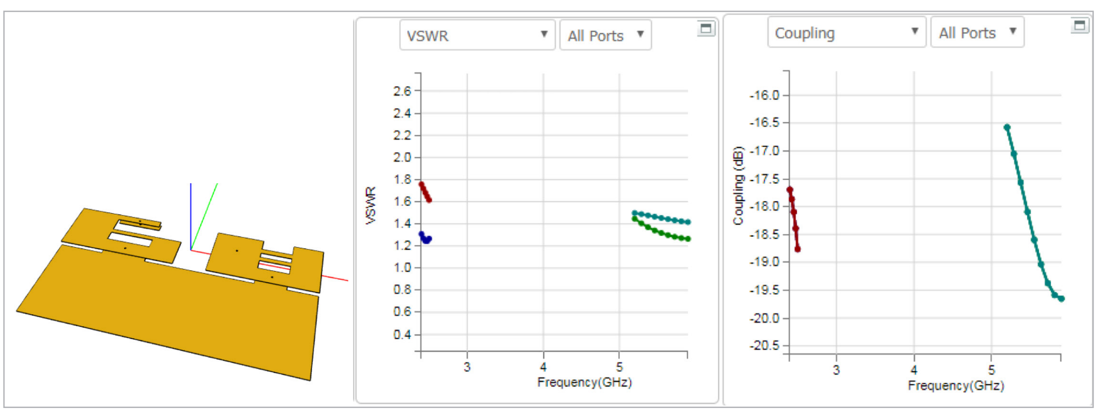

Figure 4: Two-port MIMO antenna with VSWR and coupling performance predicted by AntSyn software.

both ports, with a maximum VSWR of about 1.8:1 and a maximum coupling of about -16.5 dB. At the lowest frequency, the antenna edges are separated by less than 0.093 wavelengths and the ports themselves are only 0.41 wavelengths apart. As can be seen, the shapes of these two elements have some similarities, but are not identical. This is expected and helps improve the isolation.

This antenna was imported into AWR Design Environment, specifically Microwave Office circuit design software, and further simulated using AXIEM 3D planar EM solver across the full range of frequencies from 2 to 6 GHz. The results, shown in Figure 5, match well with the AntSyn predictions, with worst-case coupling of -16.8 dB. Note that although coupling and VSWR do rise in between the Wi-Fi bands, in-band performance is very good.

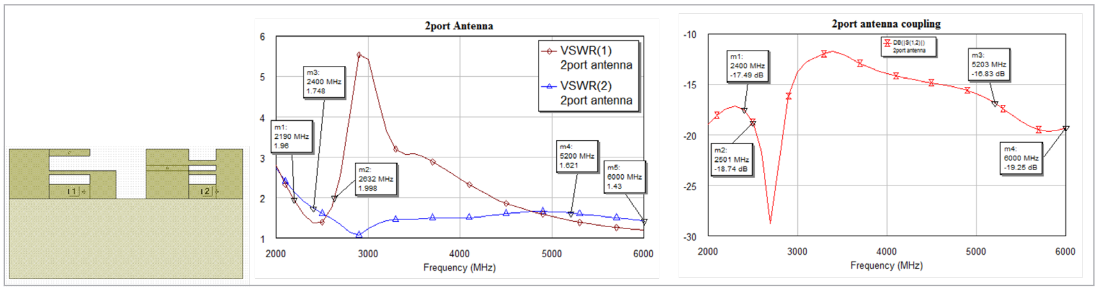

Figure 5: AXIEM simulation results.

AntSyn software was also used to optimize a three-port antenna using the specifications and size limitations shown in Figure 1. This time, a matching network was used to help improve performance with the tighter spacing.

The maximum VSWR was about 1.8:1, while the maximum coupling was -14.7 dB, which occurs between the two ports that are closest together, shown in Figure 6 as the right and center ports. Note that the spacing is only 0.163 wavelengths (at 2.4 GHz) between these ports, with a minimum spacing of 0.048 wavelengths between the elements. The distance from the center to the left port in Figure 7 is also only 0.31 wavelengths.

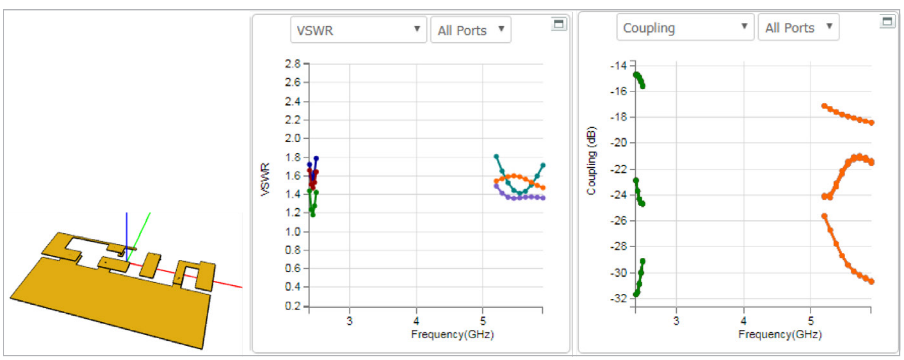

Figure 6: Three-port MIMO antenna performance as predicted by AntSyn software.

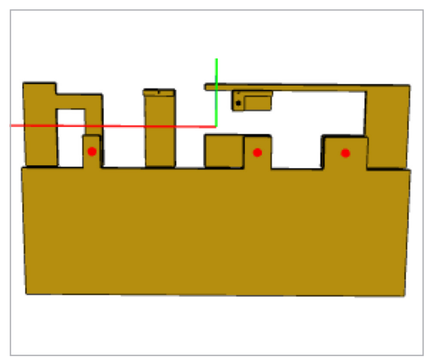

Figure 7: Bottom view of three-port MIMO antenna.

The shapes of these antennas are even more diverse than the two-port antenna. Essentially, AntSyn software created a different antenna for each port and a parasitic fence was placed between the center and left ports. All this complexity was created automatically by the software, demonstrating the inherent strength and robustness of the genetic algorithm to fully explore more of the design space and produce optimal performance MIMO antennas.

Conclusion

Demand is escalating for high-performance, low-cost antennas to provide reliable connectivity for upcoming 5G and IoT wireless devices. AntSyn software automated antenna design, synthesis, and optimization enables designers of antennas, including compact MIMO arrays, to address the challenges of next-generation antenna design and integration within mobile devices and IoT components.

Designing IoT Antennas That Make the Connection

Overview

The many different mechanical and electrical requirements for IoT devices pose challenges for antenna designers seeking the best combination of price and performance. Sensors may one day be everywhere, providing remote monitoring and control of electronic devices by means of the IoT applications. But first, those millions of IoT devices that rely on wireless communications for internet access will need antennas. Among the challenges in designing those many antennas will be the classic tradeoffs of performance for size: since many IoT devices are meant to be completely unobtrusive as they communicate to the internet, antennas will need to be compact.

But such factors as the wireless frequency band, the required communication range of the IoT device, the data upload and download rates between the IoT device and the wireless access point, even the location of the IoT device can all determine the type of antenna that best suits a particular IoT application. To complicate matters, the antenna may have to fit into an IoT device that is small enough to essentially remain invisible.

Market forecasts are predicting millions if not billions of IoT products to be sold during the next half decade, with applications spanning commercial, industrial, and military areas. Devices may be as simple as temperature sensors for remote-control thermostats to more complex security systems in warehouses. Some IoT devices may gain access to the internet using electrical wired or optical connections, but many will rely on wireless communications for Internet access, and the antenna will be a key part of that link.

Wireless internet access for IoT devices will be achieved via existing standards, such as wireless local area network (WLAN) channels (per IEEE 802.11), W-Fi, standard Bluetooth, Bluetooth Low Energy (BLE), radiofrequency identification (RFID) channels, even cellular radio signals, using Third Generation (3G) and Fourth Generation (4G) Long Term Evolution (LTE) wireless networks. The choice of wireless access will play a role in the functionality of any IoT device. A wireless standard such as BLE, for example, can provide short-distance wireless communications with extremely low power consumption, remaining active for extended periods on battery power.

Any IoT antenna design must be optimized for the wireless band or bands of interest. Additional capability, such as a BLE-enabled IoT product that operates with energy scavenged from co-located radio signals, can further complicate the antenna design. The various wireless standards offer different capabilities, requiring IoT antennas that support different frequencies, bandwidths, and polarization schemes, resulting in different design strategies. An IoT device, for example, may require access to multiple wireless standards, such as 4G and WLAN/Wi-Fi. Factors such as cost and IoT device package size will help a designer determine if such a case can be handled with a single antenna or if it requires multiple antennas. In addition, the advanced antenna technologies used in some wireless standards, such as 4G's multiple-input-multiple-output (MIMO) technology, used to minimize the impact of interference from surrounding radio waves, can further complicate the design of IoT antennas. Typically, MIMO signals are typically handled by means of multiple antennas or a number of antenna resonant elements in an array pattern.

Narrowband frequency coverage for a single antenna may be sufficient for an IoT design meant to work within a single wireless band. For an IoT device designed to function across multiple wireless standards, such factors as size and cost will help determine the optimum antenna solution. A single wideband or ultrawideband (UWB) antenna may provide the performance required for multiple wireless standards, including reception of global positioning system (GPS) signals for precision location, while multiple more narrowband antennas may be needed to provide the performance needed for all bands.

In some cases, even a single wireless standard may require multiple antennas. For example, an IoT device based on 3G can work with a single antenna while an IoT device using 4G for internet access may need at least two antennas in support of that standard's MIMO technology. Antenna solutions for IoT devices must be small enough to be unobtrusive. Many IoT devices are meant to be invisible, such as healthcare monitoring units built into USB housings. Internal antennas for such devices must be small, typically with bandwidth optimized for 2.4-GHz WLAN/Wi-Fi use. Some IoT applications are better served by an externally mounted antenna, such as an IoT device that must connect to an access point through a wall. An IoT device's housing can also influence an antenna's mounting point, with a plastic housing resulting in minimal loss for an internally mounted antenna while a metal housing and its shielding characteristics inviting the use of an external antenna.

Sizing Up IoT Antennas

No single antenna is a best fit for all wireless IoT devices. As noted, in some cases it makes more sense to locate an IoT antenna (or antennas) outside of a product's housing, and a simple monopole or dipole antenna may provide the frequency and bandwidth needed to cover multiple wireless bands and standards. But when an antenna must be mounted internally, and size is a concern, a number of miniature antenna types are candidates for single or multiple-band frequency coverage. These include wire antennas, whip antennas, chip antennas, PCB antennas, and integrated-circuit (IC) antennas. Each approach has advantages, disadvantages, and cost differences that may guide the choice of antenna for a particular IoT product design. How do the different miniature antennas for IoT devices compare?

Wire antennas are relatively simple and straightforward to design, as the name suggests, and they are capable of wide bandwidths using a single device. However, the physical size of a wire antenna is wavelength dependent, meaning that, as wavelengths increase with decreasing frequencies, the size of the antenna must also increase. Wire antennas are well-suited for external placement with an IoT module, although they can also be mounted internally given adequate package size. In manufacturing, it can be challenging to achieve good performance repeatability with wire antennas, making them a better match for lower-volume applications.

Whip antennas tend to be the most expensive and largest of the IoT antenna types, although they are capable of excellent performance. As with wire antennas, they typically require a coaxial cable, coaxial connector, and a coaxial launch to connect with IoT PCB-based transceiver circuitry, although the external antenna provides mounting flexibility when installing an IoT module.

Chip antennas are formed by means of metallization on a ceramic substrate, such as low-temperature-cofired-ceramic (LTCC) substrate. These antennas can be made extremely small and treated in IoT circuit assembly much like any SMT component. On the downside, they are limited in bandwidth and efficiency, and sensitive to ground-plane variations.

PCB-based antennas, such as the patch antennas commonly used in mobile telephones, are capable of wideband frequency coverage and relatively low in cost, since they are formed by etching patterns on the same PCB that holds the IoT transceiver. However, a planar antenna can occupy a large area on a PCB and increase the size of an IoT module.

IC antennas are perhaps the smallest but most complex of the IoT antenna options, although such active antenna designs are capable of wide bandwidths and multiple wireless bands. They can be integrated with additional functionality, such as voltage regulation and temperature sensing for stable performance over wide temperature ranges. Like passive chip antennas, they can be mounted like SMT components on a PCB, although they require a power supply and the associated bias circuitry. IC antennas are ideal for high-volume applications, but fabricating such antennas, which requires time at a commercial semiconductor foundry, can be expensive.

Antennas mounted internally in an IoT device, particularly PCB-type antennas, will contribute to that EM environment and will impact the overall circuitry. While the performance of a PCB antenna alone can be known, that performance is never totally independent of an IoT's associated wireless transceiver circuitry, and the combined performance can vary from the measured performance levels of the separate circuit portions.

For this reason, it is useful to take advantage of design help from proven antenna models and computer-aided-engineering (CAE) simulation software before committing to a prototype IoT circuit and antenna design. Such simulation software makes it possible to change input parameters for different design scenarios to better understand the results of the parameters on antenna and IoT system performance. As an example, the software could be used to weigh the performance tradeoffs between a patch antenna fabricated on low-cost FR-4 circuit-board material versus a more expensive PCB material with more tightly controlled dielectric properties.

AntSyn synthesis software within the AWR Design Environment platform provides design support beyond standard simulation software. This cloud-based (available online through any standard browser) software-as-a-service (SaaS) provides antenna design, synthesis, and an optimization tool that allows users to see the effects of their requirements on output antenna performance, for many different types of RF/microwave antennas. The flexible and easy-to-use software can design single- and multiple-band, broadband, patch, wire, horn, phased-array, even multi-function and dual-polarization antennas.

AntSyn software uses powerful EM optimization based on proprietary genetic algorithms to explore more design space and accelerate the early phases of the antenna design process (Figure 1). The software features a browser-based interface with intuitive operation. It includes a diverse database of proven antenna design "seeds" with geometries that are effectively modified to meet the desired performance and size requirements entered by the user. If the user does not select an antenna template as a starting point for optimization, AntSyn software will select antenna templates automatically based on the specifications entered.

Figure 1: The Antenna Library screen in AntSyn software shows some of the many antenna models that can be used as starting points for design and simulation.

Performance requirements include frequency, bandwidth, impedance, antenna gain pattern, polarization, and return loss or VSWR, in the form of a blank data sheet for each antenna design. Maximum antenna size can also be specified, along with some basic geometric layout parameters, which is very important for IoT devices. Once AntSyn software is run, it provides completed designs, CAD files such as STEP that can be downloaded, and simulated results in familiar formats, such as gain versus frequency and return loss versus frequency, for ease of comparison with measured results (when building that prototype).

For those who need further analysis, AntSyn software can export design data to commercially available EM simulation software (Figure 2). For higher-level simulations, the tool can export data to full-featured circuit/system simulation software tools within AWR Design Environment software, where EM simulations of an antenna design such as a PCB antenna can be combined with simulations of the active circuitry of an IoT module to gain insights into the interactions between the antenna and the IoT transceiver circuitry.

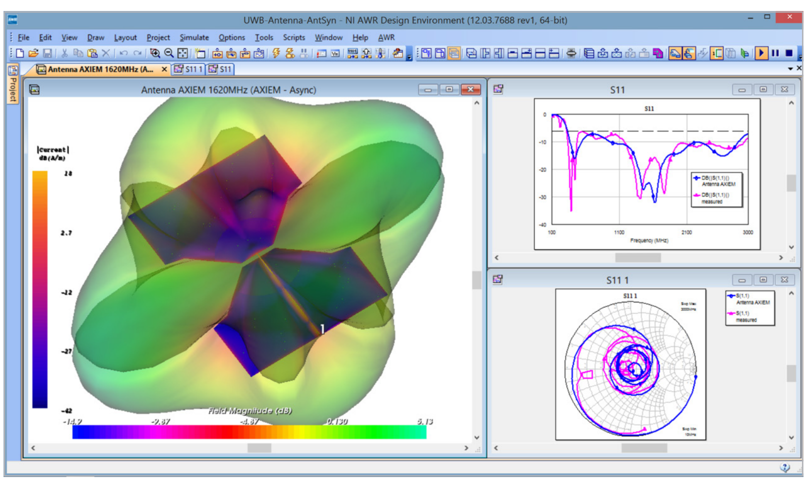

Figure 2: By exporting data from AntSyn software to an EM simulator, detailed 3D field studies can be performed on an antenna design.

Conclusion

Antennas are often one of the last components considered in the design of an IoT product, although the choice of antenna can have an impact on the size and performance of the IoT device. Fortunately, software design tools such as the AntSyn antenna synthesis and optimization tool provide designers with an efficient tool to quickly explore different antenna types, different layout/geometry choices, and design parameters prior to committing to a physical prototype. The software makes it possible to try different antenna types when searching for the best match for the target IoT system performance parameters and wireless bandwidths.

Fractus Antennas Innovates Miniature Antenna Components

Case Study

Fractus Antennas designs matching networks for a new class of off-the-shelf, surface-mount technology (SMT) chip antenna components called "antenna boosters" based on the company's proprietary Virtual Antenna™ "antennaless" technology. The challenge faced by Fractus Antennas designers is that the antenna booster component, which fits within any application, mobile/IoT, and/or device, needs a matching network that is more sophisticated than the typical T or Pi network needed for a conventional antenna. Figure 1 is a picture of the new antenna booster.

The design team chose Microwave Office circuit design software as the ideal complement for Virtual Antenna, describing it as "a smart software with great optimization and tolerance analysis features that helps to complete the design from concept to production in a fast and effective way."

Microwave Office software provides a number of optimization and tolerance analysis tools that helped the team design the sophisticated matching networks needed for Virtual Antenna, as shown in Figure 2. The matching response became "live" with the smart tuning elements, providing key insights on the role of each component in the network and providing the exact values for the optimal design. In addition, tolerance analysis enabled the team to assess and tune the final and production-ready designs, making the whole design process productive, reliable, and effective.

Figure 1: Fractus Antennas antenna boosters fit seamlessly within any application, mobile/IoT band, and/or device.

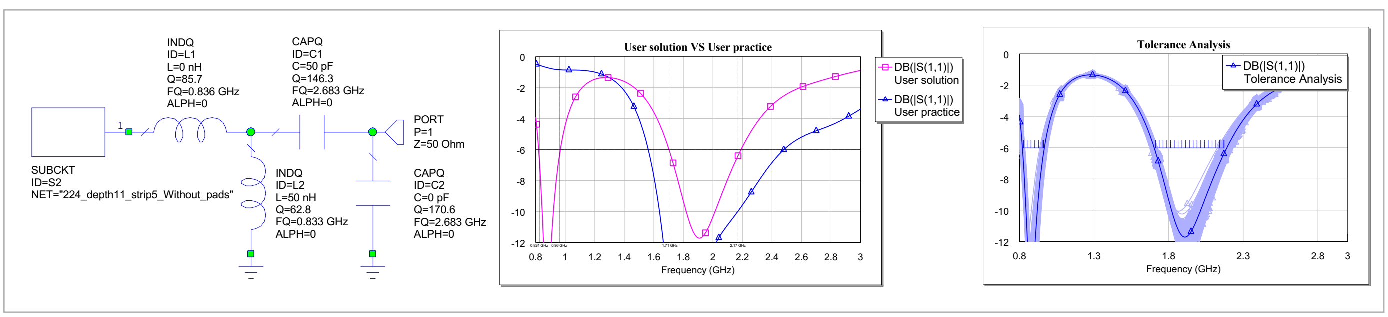

Figure 2: Microwave Office software provides optimization and tolerance analysis tools that were useful for designing the matching networks for Virtual Antenna.

The key benefits of using AWR software together with Virtual Antenna technology are twofold: the reduction of design time and the accuracy of the solution. The powerful tools such as the smart tuning and optimization function significantly reduced the time for simulating the most appropriate matching network for each particular design. Once the proper matching network topology is selected, AWR Design Environment software enabled the team to reduce the simulation time by a factor of 10 over a manual design, while at the same time providing highly accurate solutions.

The combination of "live tuners" for the network components, the ability to integrate real, commercial, off-the-shelf components from AWR software libraries, and the tolerance analysis and optimization tools were the most beneficial features of the software.

Conclusion

The IoT ecosystem consists of a vast and diverse network of sensors, gateways, and infrastructure operating across different configurations, frequencies, power requirements, and protocols. Developing cost-effective IoT solutions requires a smart, organized approach to radio and antenna integration within a design flow that PCB (and enclosure) characterization, antenna and RF front-end component modeling, impedance-matching network design support, and proper interconnectivity between the design layout and simulation tools. AWR software provides the RF simulation, EM analysis, and automation to address these challenges from a methodical and low-risk approach. Using a modular design methodology, engineers can focus on combining all the relevant components in the RF signal path, including the supporting PCB substrate and/or the device enclosure, into a hierarchical simulation network for analysis prior to manufacturing and test.

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