FOR BLUETOOTH TO BE FEASIBLE, THERE MUST BE AN UNDERSTANDING OF PRODUCT VALIDATION AND PRODUCTION TEST.

Bluetooth-IC testing meets chip design

BLUETOOTH IS SIMILAR to other communication devices in that its elemental form consists of a transmitter module, a receiver module, and a controller module. You can find these elements in modem, serial-line-card, codec, and Ethernet applications. Validating these communication devices is a two-step procedure in which a design team verifies the performance of the device, and a third party then verifies both performance and interoperability. Production testing of Bluetooth ICs uses similar methods that are common to all the previous transceivers. However, because of the cost constraints of Bluetooth, designing for “cheap”-IC testing is necessary.

BASIC BLUETOOTH

A Bluetooth system comprises an RF unit, a baseband-link-control unit, and link-management software (Figure 1). In general, the receiver section is the most difficult section to design and to test. Receivers must downconvert and demodulate the RF signal under frequency-hopping control. You use a VCO (voltage-controlled oscillator) to recover the clock and the data. The receiver then forwards the signal to the baseband unit. The transmitter upconverts the baseband information to the frequency-modulated carrier, passing it through frequency-hopping and bursting circuitry before transmitting it to the outside world. This Bluetooth design emphasizes low power, low cost, and robust operation. The link-control unit and the link-management software determine the device status and establish the network connections, error correction, and encryption. The link-management system also lets you define transmit and receive frequencies, manage power control, control RF frequency hopping, and place the device into a test-loop-back mode, which facilitates frequency, power-control, and packet testing.

At the system level, testing takes minutes to exercise all of the air-to-air functions. The test setup consists of establishing a piconet, in which the tester acts as a master, and the system under test acts as a slave. The link-manager protocol controls and configures the system. A series of prescribed tests exercises the transmitter under various conditions: varied packet types, pseudorandom-sequence-function verification, hopping-sequence verification, transmit-parameter-control verification, power control, and frequency switching. A loop-back test follows these tests, essentially testing the receiving section of the system.

At the chip level, testing takes seconds. Chip testing focuses on verifying the correct power and frequencies of the transmitter and the sensitivity of the receiver, using a variety of test modes to verify the functionality of the silicon and obtain a measure of its performance. However, from the total-system-cost point of view, it is best for you to align the chip testing with the system testing. Doing so permits bet-
ter correlation of results and reduces test-coverage issues.

**DESIGN VALIDATION**

In the past, design validation of communication devices was block-based. Each block had stimulus and observation paths off the chip. For example, you could characterize the antialiasing, receiving, and smoothing filters of a modem. However, as the frequency of communication devices increases, any attempt to examine the high-speed path can cause signal-integrity problems. The act of making a measurement can distort the results. Thus, you should not directly test the transmitting or low-noise amplifier. An indirect method, such as loopback, is preferable.

The Bluetooth specification describes the test requirements for certification (Reference 1). In general, the validation methodology can follow one of four approaches: loop-back of the receiver into the transmitter, loop-back of the transmitter into the receiver, digital control of the transmitter, and analog control of the receiver. Direct digital control of each of these approaches, or test modes, is the preferred approach; however, you can control the test using the given RF protocol.

**TRANSMITTER VALIDATION**

Loop-back of the receiver into the transmitter is one of the better methods for qualifying a transmitter. It requires a digital-signal generator to input a signal into the receiving section and loop the subsequent signal back through the transmitter for analysis (Figure 2). The difficulty of this approach is in determining the best place for the loop-back to occur. Typically, the loop-back occurs before the downconversion, but this method fails to exercise much of the receiving-and-transmitting circuitry. Looping back after the downconversion increases design difficulty. The resulting signal requires a spectrum analyzer, a vector-signal analyzer, or a power meter to perform the measurements. Instrumentation must be able to trigger on a burst packet, given that the Bluetooth signal is a sequence of time-division-duplicated bursts.

One alternative is to provide a means for generating a digital word that applies to the transmitting section. Preferably, you can generate this digital word on chip or read it from a memory device to provide a continual transmitter signal; otherwise, you must make provisions to provide an externally generated word. An added complexity of signal analysis is the Bluetooth requirement for frequency hopping. Frequency hopping occurs over 79 channels (22 channels in Spain, France, and Japan). To simplify analysis, hopping must be controllable, meaning you must be able to turn it on or off. Additionally, you must be able to select some different channels.

The Bluetooth spec also requires that you test the transmitter’s output power (average and peak), power density, power control, transmit-output spectrum, modulation characteristics, initial carrier frequency, and carrier-frequency drift.

**RECEIVER VALIDATION**

To validate the receiving section, you must primarily use a test approach that requires analog control of the receiver, in which a digital source that can generate a Bluetooth-modulated signal applies a signal to the receiver input for processing. You can remove the processed signal after it passes through the demodulator and clock recovery for analysis or after it passes through the baseband processor for analysis (Figure 3). You can also use the previous loop-back mode, in which you analyze the signal through the transmitter.

The receiver measurements for Bluetooth are sensitivity (single-slot and multislot packets), carrier-to-interference performance, blocking performance, intermodulation performance, and maximum input level.

**TEST FIXTURES**

Note that the baseband frequency of Bluetooth is 1 MHz, and the carrier frequency of the system is 2.4 GHz. This carrier frequency places severe constraints on the cabling and test fixtures you place on the device. RF pc boards are characterized by low complexity, precise impedance matching, high feature accuracy, and low or uniform dielectric constant. The boards generally have only one or two layers.

The focus of the test fixture is maintaining signal integrity. The major problems that contribute to signal loss are transmission-line effects, impedance mismatching, and reflections. Consequently, correlating the design validation with the production test is a difficult task. One major source of discrepancies depends on how well the part contacts the test fixture: In the design-validation environment, you can solder the device under evaluation directly to the pc board, whereas in the production-test environment, you must press the device onto the test fixture. In addition, run-to-run variations in the IC and packaging can lead to erroneous conclusions. To aid in this correlation, the validation fixture and the production test fixture should be virtually identical.

**PRODUCTION TESTING**

Production testing of any communication device focuses on qualitative measurements. Bluetooth is no different. The production-test environment is more challenging because of longer connections to power and ground, longer connections to the instrumentation, and the fact that the surface is not ideal for making contact with various parts. Equipment on the test floor also provides a noisy environment that may impact chip performance. Often, the tests in production are a subset of the validation tests. The emphasis, however, is on a stable and repeatable suite of tests.

You can divide production testing into two parts: testing the baseband and testing the RF blocks. (Figure 1) The baseband block comprises digital subblocks, consisting of a controller, a microprocessor, memory, and an assortment of I/O. The RF block is a mixture of analog and digital subblocks, consisting of frequency-hopping control, filters, a modulator, burst control, a demodulator, a transmitting amplifier, a low-noise amplifier, and attendant clock circuitry.

---

**Figure 2**

The receiver-to-transmitter-loop-back test method requires a digital-signal generator to input a signal into the receiving section and loop the subsequent signal back through the transmitter for analysis.
ic-test-program generation, and I_{DDQ}. Embedded memory can cause complications, so some form of built-in self-test exercises the memory. The embedded memory (depending on the memory size) may also require a burn-in to ensure reliability. You should also implement test modes so that they continually cycle. Such cycling in combination with the RF block generates a given frequency signal that aids in determining the functionality and performance of the Bluetooth system.

Testing the RF block is interesting and difficult. In the days of modem testing, concern arose that the noise from the faster digital circuits would affect the performance of the slower analog circuits. Now, there is equal concern that the noise from analog circuits will affect the performance of the digital circuits. Consequently, designs must contain adequate V_{SS} connections.

Testing the receiver through analog control plays the foremost role in these circumstances. It uses the loop-back path from the transmitter to the receiver by applying a given digital word to the transmitter section, upconverting it, looping it back into the receiver section, and then downconverting it back into a digital format (Figure 4). You must make allowances, because this test mode may not reflect what you see in the field operation of the chip.

Again, loop-back occurs at the baseband frequency because signal-integrity effects may cause erroneous conclusions if the loop-back occurs on chip. To avoid this situation, the tester itself may contain a Bluetooth demodulator and modulator. One benefit of this arrangement is that, although you conduct the system test in a similar fashion, you use two sets to determine connection and transmission. At this point, you could implement tests that the Bluetooth specification mentions.

You can supplement the loop-back test with a transmitter-section test followed by a receiver-section test. Implementing these tests verifies that the device can transmit and receive over the Bluetooth specification. Judicious testing results in designs that can hold their ground in the field.

IC-DESIGN RAMIFICATIONS

Chip design may generate test chips for each of the IC blocks, buying the IC-block intellectual property and then performing the integration, or a combination of both. For example, you may design an FM modulator and demodulator on the test chip. Once you debug these blocks, you can integrate them onto one chip with the remaining components. Alternatively, you can purchase and integrate modulator or demodulator blocks. In theory, it is a simple matter of putting the respective blocks together. However, in practice, the interactions and coupling between the blocks, the silicon substrate, and the package itself pose a difficult challenge. Using the following test modes helps you with validation and production-test development:
- loop-back from the receiver to the transmitter before demodulator,
- loop-back from the receiver to the transmitter after demodulator,
- digital control of the transmitter,
- analog control of the receiver,
- loop-back of the transmitter to the receiver,
- on-chip generation of test words, and
- PLL measurement via a divide-by-24 signal.

These test modes do not shut off any of the major blocks, so they provide a relatively accurate picture of the silicon performance.

The Bluetooth specification recommends only the loop-back-from-receiver-to-transmitter mode, but all of the test modes facilitate verification and production testing.

References
1. Bluetooth RF Test Specification, Version 1.0B.

Author’s biography
Howard Woo is manager of product and test engineering at ADMtek Inc, where he has worked for four years. In his current position, he performs IC-product validation, arranges and implements IC testing and product support, and supports quality and reliability engineering goals and objectives. Woo has a bachelor’s degree in science from the University of Toledo (Toledo, OH) and a master’s in physics from San Jose State University (San Jose, CA). In his spare time, he enjoys traveling and has visited Egypt, Turkey, Greece, Italy, France, Germany, the Netherlands, Spain, Japan, and China.