

TESTDIGEST

RF TEST

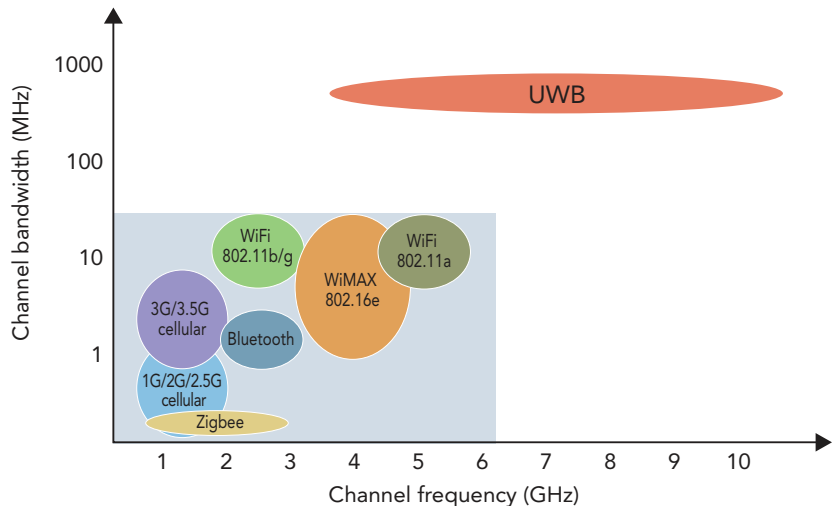
Demystifying production test of UWB devices

Numerous technologies are emerging to meet consumer demands that traditionally wired products “cut the cord” and move into the wireless domain. One example is ultra wideband (UWB), a communications technology for transmitting data over channel frequencies of 3.5 to 10.5 GHz—frequencies that are used for the wireless video and USB 2.0 signals in numerous household products and appliances.

The emergence of UWB technology, however, creates both economic and technological challenges. On the economics side, the addition of the UWB communication interface must not add significant cost to the consumer product (television, DVD player, digital camera, etc.). The initial price target for a four-chip UWB set—including an RF front end, an RF transceiver, a digital base-band IC, and a media access controller (MAC)—is less than \$15.

On the technology side, UWB has unique attributes—such as its wide range of channel frequencies and its 528-MHz bandwidth—that can make testing these devices in high-volume production very challenging.

In particular, as the ultra-wideband name implies, the modulation bandwidth that the device employs is an or-



UWB's bandwidth and channel frequencies present significant test challenges, but you can meet them using standard production testers coupled with creative DFT techniques.

der of magnitude larger than even the latest wireless LAN (WLAN) or WiFi devices. Because the technology has some nontraditional test requirements, it is very difficult to use a traditional production test strategy for UWB devices.

But despite what you may think, you don't need specialized test equipment to test UWB devices. It is possible to meet device manufacturers' test requirements by using a mixture of familiar tech-

niques combined with design-for-test (DFT) creativity. While there are daunting challenges in the testing of UWB devices, a solution can be found on readily available production testers that minimizes the test cost per device. The online version of this article details the test challenges and describes how you can meet them (www.tmworld.com/2007_12).

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A practical approach to production test of UWB devices: Part 1

As consumers demand that traditionally wired products “cut the cord” and move into the wireless era, technologies are emerging to meet that demand. One such technology is ultra-wideband (UWB). UWB allows for communication rates that can be applied in household products that, for example, transmit wireless video or support wireless USB 2.0.

The emergence of this technology, however, creates several challenges—both economic and technological. On the economic side, the addition of the UWB communication interface must not add significant cost to the consumer product. Regarding technology, UWB has some unique attributes that can make testing these devices in high-volume production very challenging. In particular, as the ultra-wideband name implies, the modulation bandwidth that the device employs is an order of magnitude larger than even the latest wireless LAN (Wi-Fi) devices. Because UWB technology has some non-traditional test requirements, it is very difficult to approach UWB devices entirely with a traditional production test strategy. This article will explore those challenges to show that there are ways to meet device manufacturers’ test requirements using a mixture of familiar test techniques combined with some design-for-test (DFT) creativity in order to minimize the test cost per device. While there are some daunting challenges in the testing of this technology, a test solution can be found on readily available production testers, without a need for specialized test equipment.

What is ultra-wideband?

The term ultra-wideband (UWB) describes an unlicensed radio technology that occupies channel bandwidths of greater than 500 MHz (Ref. 1). UWB’s channel bandwidth is a major departure from existing narrowband and wideband wireless standards. Narrowband technologies such as those employed in 1G/2G/2.5G mobile phones, generally occupy less than 2 MHz, where wideband tech-

nologies such as 3G mobile phones and wireless LAN (Wi-Fi) generally occupy 3 MHz to 40 MHz. UWB technology provides a personal area network (PAN) at high communication rates over short distances. It can provide PAN coverage in many of the same applications as Bluetooth and Wi-Fi, however, at much greater data rates.

This ultra-high speed, short-range RF technology has application uses in many of the household consumer appliances, such as DVDs, digital TV set-top boxes, digital TVs, PCs, and printers. In addition, UWB shares its technical roots with radar technology and has possible application usage in the collision-avoidance automotive space as well as penetrating radar, which can be useful in law enforcement.

Why is there so much excitement around UWB?

The portability of PC technology in smart-phone and other mobile devices is putting the ability to manage a significant amount of data in the consumer’s pockets (music, photos, email, file-sharing, etc.). The need for fast and efficient transmission of that data between mobile devices, even faster than Wi-Fi, is driving a requirement for a wireless path to do so.

What does “ultra” wide bandwidth allow? There is a relationship due to Shannon’s law (Ref. 2) between the data rate, bandwidth of the signal, and signal to noise ratio (SNR) that is dictated by

$$C = BW \cdot \log_2(1 + \text{SNR})$$

where C is channel capacity in bits per second, BW is channel bandwidth in hertz, and SNR is the signal to noise ratio.

The major implications of this equation are that increasing the data transmission rate of a signal can be accomplished either by increasing the occupied bandwidth, the SNR, or both. SNR can loosely be correlated to transmitted power, or more importantly, battery consumption in the case of mobile applications. UWB seeks to operate in a small signal to noise

environment to minimize power consumption. Because of the ultra-high bandwidth, UWB allows for an efficient use of mobile power while still achieving a very high rate of data transmission.

There are several other advantages to UWB technology. First, the energy in a transmitted UWB signal is spread out in such a large bandwidth; the signal is unlikely to interfere with another communication system because the signal power at a specific frequency is seen as noise to the other system. Likewise, a UWB receiver accepts such a wide bandwidth that a powerful narrowband signal is unlikely to interfere, because most of the transmitted information will be outside of the interfering signal.

In addition, since the transmitted power of UWB is so small, it is a mobile-friendly technology that consumes little power—significantly less power than Wi-Fi. The down-side to the lower power—combined with the physical nature of higher frequency signals—is short range of operability, which makes UWB suited for a personal network rather than a wide network.

The market adoption of UWB

While the application usage of UWB looks to be various, UWB’s primary market challenge is the adoption of a common standard. A task group was assembled to define the UWB standard, which was identified as the IEEE 802.15.3a working group. Initially, there were two competing approaches to UWB, both of which are backed by large companies. The technology suffered a setback in early 2006 when the task group could not come to an agreement on the standard’s definition, and voted to disband (Ref. 3).

Competing standards

One of the competing factions in UWB was the MBOA Alliance, which proposed a multi-band orthogonal frequency division multiplexing (OFDM) approach to UWB. This method divides the entire bandwidth into smaller parallel sections; it

borrowed largely from the same techniques used in WLAN's 802.11a/g. This technique has the advantage of being more robust in a noisier environment, maintaining a high rate of data transmission. In addition, the technique allows for scalability and the coexistence with other OFDM systems like Wi-Fi. The counter approach to MBOA proposed for UWB is a direct-sequence approach, which instead of breaking the spectrum into pieces, utilizes the entire band. This approach works by sending billions of pulses across the transmitted spectrum. While this technique is also fairly robust against interfering signals emitted from other transmission sources, its primary advantage is that it is a simpler approach in its implementation (Ref. 1).

The lack of adoption of a single standard for UWB is affecting its adoption in the consumer marketplace. Initially, UWB intended to be the primary technology in wireless video applications. Digital TV requires approximately 50-Mbps digital transmission rate for standard-definition television. Even though Wi-Fi is currently capable of 54-Mbps data rates (802.11a/g), the effective data rate is actually closer to 35 Mbps due to overhead in the protocol. However, Wi-Fi is now rolling out devices capable of up to 100-Mbps data rates through the 802.11n standard, which has the added advantage of backwards compatibility to devices that utilize the very popular 802.11g Wi-Fi standard.

UWB's commercial outlook

The longer that UWB takes to reach a standard implementation, the more diffi-

cult it will be to find commercial success. Because Wi-Fi is making quick strides in the wireless-video application space, UWB is looking to find a "killer application." One likely candidate is wireless USB, where the required data rate is up to 480 Mbps, which far exceeds the roadmap of Wi-Fi. In addition, USB applications are generally in extremely close proximity to each other (less than three meters), which also fits well with the UWB requirements. A working group, the WiMedia Alliance (www.wimedia.org), is attempting to standardize a wireless USB interface based on UWB technology. WiMedia's approach offers some technical advantages in this application space which allow multiple radios to operate in a highly dense environment.

UWB could replace most of the USB cables between the PC, mouse, keyboard, printer, scanner, external storage media, mobile phone, and portable music player. It would also be a common network interface between all of these peripherals, which would be a significant improvement over the wireless keyboard and mouse products available today in the desktop market. It would allow interoperability between devices much in the same way that Bluetooth revolutionized the hands-free audio device interoperability between different head-set and automobile manufacturers.

Because there is synergy between UWB and Bluetooth applications, the Bluetooth taskforce is evaluating the possibilities of an UWB and Bluetooth convergence. The benefit of this would be to add functionality to a mobile device, such

as the mobile phone, and would not require an additional wireless radio device—the UWB radio would effectively replace the Bluetooth radio.

Another application that requires a solution is wireless HDTV. However, even at the maximum proposed 480 Mbps data rate of UWB, it cannot address the 1.3 Gbps requirement of HDTV.

The consumer market is ready for a high-speed PAN solution. It seems only a matter of time before UWB serves the market. The unknown is the degree of success UWB will have while Wi-Fi continues its rapid growth.

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A practical approach to production test of UWB devices: Part 2

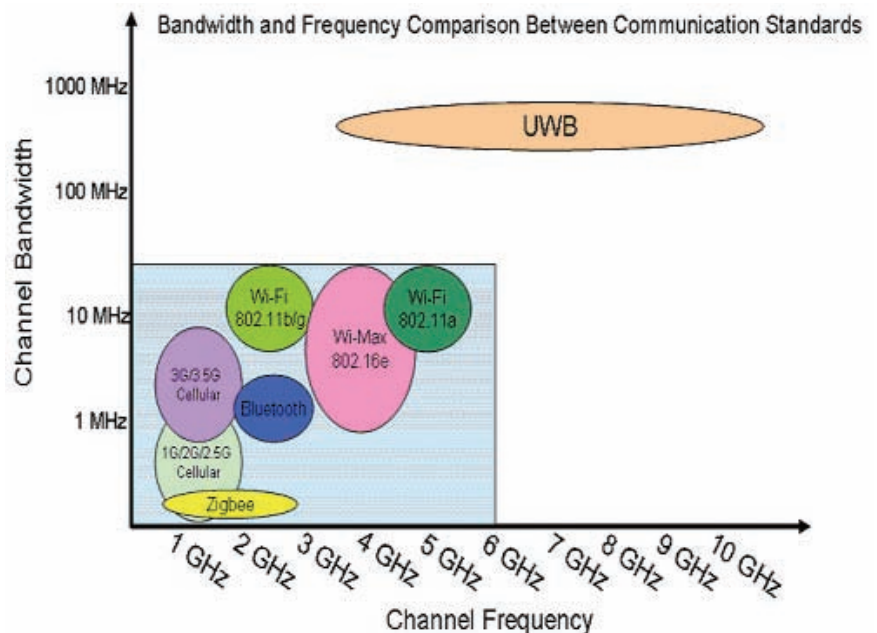
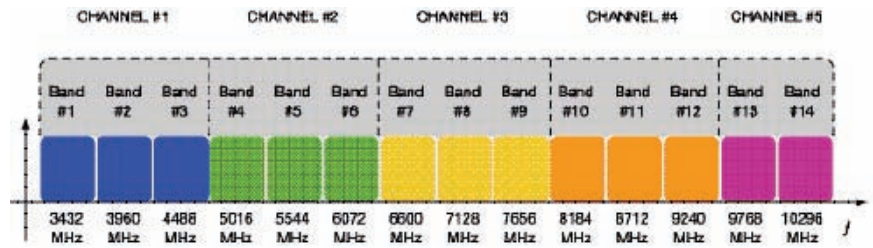
In order for UWB technology to be commercially viable, it must be very inexpensive. Consumers are not going to be willing to pay significantly more for a product solely because the wire has been removed. In other words, UWB is not going to be perceived as a value-added component to a system—it does not add features, megapixels, megahertz, or megabytes.

Because of this, the total cost for the system must be very inexpensive. The initial target for the four-chip UWB solution is less than \$15 to \$30 for the entire chip set: RF front-end, RF transceiver, digital baseband, and media access controller (MAC). Look to the selling price of Wi-Fi silicon over the last several years to see the price pressures that UWB will face after entry in the market. For device manufacturers, this means that the production, assembly, and test cost must be extremely low. This article will focus solely on the test cost. There are many challenges involved in testing UWB devices, and unfortunately, they are both economical as well as technical. In many markets, such as the high-end PC or digital TV markets, major technical challenges stem from added performance for the consumer, which allows for a higher average selling price (ASP) of the device—UWB does not have this luxury, and must contend both with the technical challenges in the face of expected low ASP.

Test challenges for UWB

As the name Ultra-Wideband implies, UWB presents a unique challenge with the bandwidth requirement: 528 MHz. Also, in order to find usable unlicensed spectrum to transmit a signal this wide, the channel frequencies range from 3.5 GHz to 10.5 GHz. Figure 1 shows the FCC frequency band allocations for UWB in the US (Ref. 1).

When looking at how these two UWB requirements fit in with other consumer devices, UWB is an obvious outlier. Figure 2 shows how different these two aspects (frequency and bandwidth) are from today's high-volume consumer wireless devices. Because of this, the production



test equipment, known as automatic test equipment (ATE), has generally been optimized to test the requirements shown in the area designated in the blue rectangle. This wireless market snapshot clearly shows that the ATE manufacturer would be wise to focus on the tight grouping of applications and serve the UWB market with an option to extend the capability of the tester.

Design validation vs. production test

To a manufacturer of UWB silicon, it is very important to understand and characterize the performance of the silicon. This is known as design validation or characterization. There are significant differences in focus between production test and design validation. For design-validation

purposes, the focus is primarily on the performance of the silicon and not on trying to cost-optimize the test solution. When moving forward with production, the key for UWB manufacturers is to identify defects rather than characterize the silicon. The cheaper that one can identify defects, the cheaper the device becomes.

Since the UWB market is under such cost pressure, the focus on testing these devices must be only two areas:

- the need to distinguish a functional device from a non-functional device, and
- the lowest possible cost.

Any other focus on collecting device parametrics in production, other than random sampling, is just a luxury that cannot be afforded in UWB high-volume production test.

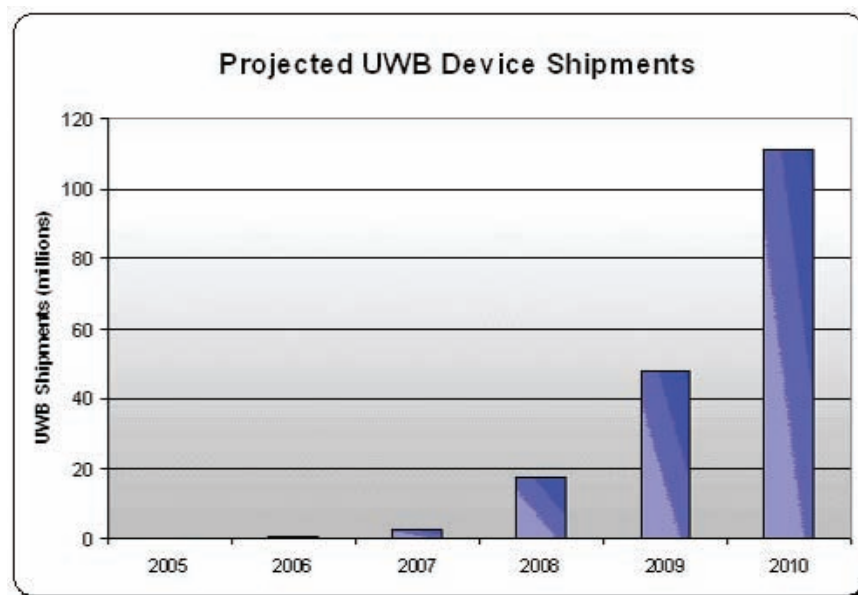
A practical approach to UWB test

In an ideal world, there is always a right tool for the job at hand. Again, as shown in Figure 2, UWB poses a challenge to the ATE manufacturer in both channel frequency and bandwidth that “breaks” the gradual evolution of technology with a very large step function. Even worse, the UWB technology driving the requirements is in its infancy, is suffering from differences of implementation, and has not yet gained any significant acceptance in the marketplace. Also, because of the delays in implementation, project volumes continue to push out. Figure 3 shows the projected production volume of UWB devices, based on Gartner’s February 2007 Ultra-Wideband Wireless Forecast.

Since UWB continues to be in the infancy of its market roll-out, this chart is probably optimistic. We can, though, make some statements regarding the relative volume of device shipments. There are generally three phases in the roll-out of a new technology:

- First phase: Early market penetration looking for an application to gain acceptance. This phase describes where UWB technology is today probably through 2008. In this phase, volume shipments are generally in the hundreds of thousands to a few million units. In this phase, the crucial factor for the device manufacturer is time to market; even more so than cost. Also, since shipment volume is small, “exotic” test solutions (that is, ones involving complicated test-fixture hardware) are acceptable, since only a very small number of the test solutions needs to be maintained. In this phase, meeting shipment commitments takes a slight priority over cost-optimization.

- Second phase: Market acceptance growing into the mainstream. This phase would involve a few key applications starting to drive the growth of UWB to adjacent spaces. An indicator for the entry into this phase would be crossing the mark of 1 million units per month, or



roughly greater than 10 million units per year. UWB likely looks to enter this phase in the 2009 timeframe. In this phase, it is still acceptable to maintain the solutions that were created in first phase; however, the device manufacturers are going to start to rely more on the test equipment vendor to provide a more robust test solution while the cost of the solution is also becoming quite important.

- Third phase: Mainstream market acceptance. This phase generally lags the second phase by a year or two since the second phase usually indicates a volume inflection point. This phase will be indicated in the UWB market when shipment volumes cross tens of millions to greater than one hundred million devices. For UWB, this timeframe is still a fluctuating guess, but looks to be in 2010 or 2011. In this phase, it is no longer acceptable to have a complicated test solution, as “copy-exact” is now crucial in this high-volume part of the life cycle. Also, cost is now the driving factor for the device manufacturer more than time to market. In this phase, as in the Wi-Fi market, device ASPs will start to decline dramatically. It is extremely crucial to have a robust and cost-effective test solution in place, and the device manufacturer will

require the test vendor to provide a turn-key solution for UWB.

A very rough rule of thumb for ATE is that one production ATE tester can test just over 6 million devices per year (assumptions: three test seconds per device and 60% overall utilization of the test equipment). Using this assumption, this means that the entire projected worldwide demand for production ATE (specifically for UWB) is roughly three testers for 2008, and approximately 18 testers for the volume in 2010.

It would benefit the device manufacturer and the ATE manufacturer to take a very pragmatic approach to testing these devices. Likewise, the UWB device manufacturer needs to its their risk by finding ways to test their devices on readily-available and existing production test solutions, as subcontract test houses will be tentative to commit significant investment in UWB testers until there is momentum behind the technology.

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A practical approach to production test of UWB devices: Part 3

Regarding test cost, we have a very good model, using Wi-Fi as an example, to provide test cost expectations for ultra-wideband (UWB). A reasonable amount of test cost per device in the wireless LAN market is in the \$0.05 to \$0.10—this is cost added to a device solely due to test. Using a simple calculation model on a mid-range RF tester at a rate of \$125 per hour in an out-source assembly and test (OSAT) house, with 60% utilization and a 3.5-s test time (including mechanical indexing time), the approximate test cost is \$0.12 per device. In order to reduce this cost towards the \$0.05 range, either a tester with a lower hourly rate must be used (generally legacy testers with lower performance), or the test time per device must be reduced (which may mean reduced test coverage).

Cost-of-test targets for UWB

Using the numbers from the previous example, in order to achieve \$0.05 per device, the test time either needs to be reduced to less than 1.5 s (including mechanical indexing time), or the hourly rate of the tester needs to be \$50 per hour. Both of these conditions are extremely unlikely, so a combination of both will need to be required.

Another technique used to reduce cost in production test is to perform “multi-site” testing, which is the concept of testing multiple devices in parallel. This is a very common technique in the mobile-phone device market. However, this model only is cost effective for devices with high volume because the economic model only works if the test equipment is fully utilized. Since the entire global UWB market is projected to be relatively small through the next couple of years, multi-site testing is not an advised option as it will not lead to significant cost reduction for any individual device manufacturer.

Native testing

Testing a device as it is going to be used in the final application is called native testing. This gives the manufacturer of the device a high degree of confidence that when it ships to a customer, it will perform to

specification. The cost model above shows another reason why a UWB-specific, native-test solution provided by the ATE manufacturer is not going to be a viable option for this market.

Native testing requirements for UWB fall into two categories: transmitter requirements and receiver requirements. On the transmitter side, a tester resource would need to stimulate a modulated base-band I/Q signal with approximately 264 MHz of bandwidth (half of the 528-MHz channel). Design validation would actually require beyond that for out-of-band measurements. Then, the test equipment would need to have the capability to down-convert a signal at up to 10.5 GHz down to an instrument that could acquire more than 528 MHz of bandwidth (preferably more than 1.5 GHz of bandwidth to be able to see the adjacent channels). The appropriate digital signal processing (DSP) would then be applied to demodulate and determine the quality of the transmitter.

On the receiver side, the test equipment needs to stimulate a modulated RF signal up to 10.5 GHz with a bandwidth of at least 528 MHz. Then, the tester would need to acquire a base-band I/Q signal with roughly 264 MHz of bandwidth. The appropriate DSP would then be applied to demodulate and determine the quality of the receiver.

Breaking this native solution into very general instrumentation, the following would be required:

- 1) RF stimulus with >500 MHz modulation capability up to 10.5 GHz,
- 2) RF receiver with >500 MHz demodulation capability up to 10.5 GHz,
- 3) base-band signal generator with >264 MHz modulation capability, and
- 4) Base-band signal digitizer with >264 MHz demodulation capability.

The immediate problem with this solution is that although items 1 and 2 are commercially available, the expense is prohibitive in a production environment, particularly because of the 528-MHz modulation/demodulation requirement. Most off-the-shelf signal generators can handle only up to 100-MHz modulation capabil-

ity. Items 3 and 4 are more feasible in an ATE environment (though expensive), but are useless without 1 and 2.

Again, the solution is directed away from native-test techniques. If native testing is an absolute requirement for initial production lots, it is advisable to incorporate the instrumentation from the design validation testing into the ATE environment. This will not yield an inexpensive test solution; however, it will guarantee quality.

Design for Test

Because a native-test solution for UWB looks to be a very unlikely candidate for high-volume test, the UWB device companies can consider some steps to make testing easier for these devices. In addition to digital scan techniques that have been largely adopted for testing the quality of the digital sections of the device, the following example techniques can be adopted into the design process to provide greater test coverage. These can allow the device manufacturer to take a more proactive position in finding a test solution for their silicon:

- **Built-in self test (BIST).** For devices with integrated baseband, a BIST technique can be used. An example of this would be a test mode that internally loops the UWB transmitter to the UWB receiver. This can be thought of as “RF scan” because it would allow the entire end-to-end chain to be functionally tested by sending in digital bits into the transmitter, and compare those to the digital bits that are received by the receiver. While this won’t tell anything about the quality of the RF signal, it will tell the manufacturer that the device is functionally viable.

- **Analog test modes.** For discrete transceivers that do not contain the baseband, an analog test mode can be added for additional test coverage on the transmitter. This would be accomplished by adding digital-to-analog converters (DACs) inside the device to generate the output spectrum. As mentioned above regarding native testing, generating the base-band signals with greater than 264 MHz of bandwidth is going to be expensive, due to

the specialized equipment required. (Refer back to Figure 2 in part 2 to see how specialized the UWB market is). This test allows for spectral purity tests to be performed without the use of specialized baseband instrumentation.

- **“Golden device” testing.** Essentially, this technique tests the device with a known-good device. This is particularly useful on the receiver side because, as mentioned above regarding native testing, most commercial RF frequency generators do not allow for the modulation bandwidth required by UWB. While the signal generators that are used in design validation can be also used in production test, the cost makes it impractical for production test. Golden device testing is viable particularly in the first phase of UWB roll-out since only a very small number of test fixtures will need to be maintained. In order to use this technique, the “golden” device must be very well understood through characterization, which makes this technique difficult to apply across many test fixtures.

- **Frequency conversion on the test fixture.** As mentioned, the channel frequency of UWB exceeds the traditional frequencies supported by commercial production test equipment (UWB requires up to 10.5-GHz channel frequency). In order to provide test coverage for the high frequency requirement, the device manufacturer can place circuitry to up-convert lower frequencies to higher frequencies from the tester to the device or down-convert higher frequencies from the device to lower frequencies that the tester can natively measure. This technique, as in golden device testing, is viable in low-volume application. It becomes less manageable to maintain across many test fixtures, but certainly can be used when time to market is driving the requirement.

The remaining test coverage for UWB devices can be provided using traditional continuous-wave (CW) methodologies. Yield analysis will also be a useful tool in reducing the cost of UWB production test. This allows the manufacturer to remove tests based on the rate of failure, thereby effectively reducing the test time. If a test never fails, testing that particular parameter wastes valuable milliseconds.

With a practical approach to UWB pro-

duction test, a combination of at least one of the techniques above combined with traditional methods can be used. By implementing these techniques, UWB can be tested on traditional production test equipment without the need for specialized test solutions. Requiring a “special” test solution can introduce risk both because of cost and availability.

Channel-frequency challenge in high volume

This discussion regarding a DFT or practical approach to testing UWB in lower volumes naturally leads to the question of how to approach the high-frequency requirement in a higher volume environment. As mentioned before, exotic test fixtures are acceptable in the early adoption phases of UWB, but the test-equipment manufacturer must provide a viable high-volume solution if UWB is to have market success. This solution must also be commercially viable for the test equipment manufacturer.

It is clear that a solution must be provided for the higher frequency UWB requirements; the approach to that solution must also match overall market conditions. Again, by using Figure 2 in part 2 as a wireless market guide, simply redesigning production test equipment to address greater than 10.5-GHz frequencies would solve the technical challenge for UWB customers. However, this would create an economic problem for all other wireless device markets.

Customers in the mobile-phone business, for example, would be purchasing capability that they could not possibly use. In addition, for the subcontractor test market, it is common to price hourly rates based on the overall configuration of the test equipment. This additional capability in the test equipment could increase hourly rates for all customers, not just UWB customers.

A more pragmatic approach to this challenge is to add an extension to the existing frequency capability of the ATE. This would essentially put the frequency up-conversion and down-conversion responsibility suggested in the DFT techniques into the ATE manufacturer’s hands. This is a significantly more robust technique for

the device manufacturer because the test fixture is significantly simplified, and any “copy-exact” issues between test setups are now handled by the standard calibration of the tester. This means that device manufacturers can expect that from tester to tester they will achieve repeatable and reliable performance. This approach, though certainly not an insignificant challenge, is a conceptually simple extension of a tester’s existing capability while not adding significant cost to the test solution.

This allows the existing testers to intersect the market requirements of UWB as it progresses from the early adoption phase into accelerated growth with the drive on production repeatability and lower cost. It allows device manufacturers to use the test solutions that they have in place today for initial volumes, with a low risk upgrade path as the market develops. In addition, this allows for configuration flexibility since not all of the RF tester resources need to be upgraded to allow for test at frequencies greater than 10.5 GHz. The main key is that no specialized new test platform is required now or in the future.

The future of UWB and production test

The consumer market is ready for a high-speed personal networking solution, and UWB seeks to fill this need. There are still several obstacles between UWB and commercial success. Beside the technical challenges mentioned, it is imperative that UWB manufacturers arrive at a standard implementation in order to achieve wide success in applications like USB. Otherwise, it will be relegated to focused solutions in the marketplace. The test requirements, though challenging, are becoming well understood by ATE manufacturers. As UWB becomes a high-volume device technology, test equipment manufacturers seek to fill their customers’ needs with a low-risk and cost-effective solution. Because of UWB’s targeted entry in the consumer market, manufacturers must seek to use a combination of DFT and traditional methods on existing test platforms to get their devices to the end consumer—the gross margins of the UWB chipset will not allow for a unique and specialized test solution.