AN3187
Application note

Manufacturing test guidelines for the STM32W108 platform

1 Introduction

Most customers have standard product manufacturing test flows, but some do not incorporate RF testing. This document describes the different options for integrating RF testing and characterization into your standard test flows. This application note is intended for customers who are moving from the early prototype development stage to the manufacturing production environment and need assistance with manufacturing test. The specific target audience is test engineers developing test processes for their EmberZNet™ -enabled products.

This application note applies to STM32W108 devices and stack releases EmberZNet™ 4.0 and later.

Device programming is not discussed in this application note

If after reading this document you have questions or require assistance with the procedures described, please contact an STMicroelectronics support at http://www.st.com/mcu, STM32W section.

Contents

2 Manufacturing test flow

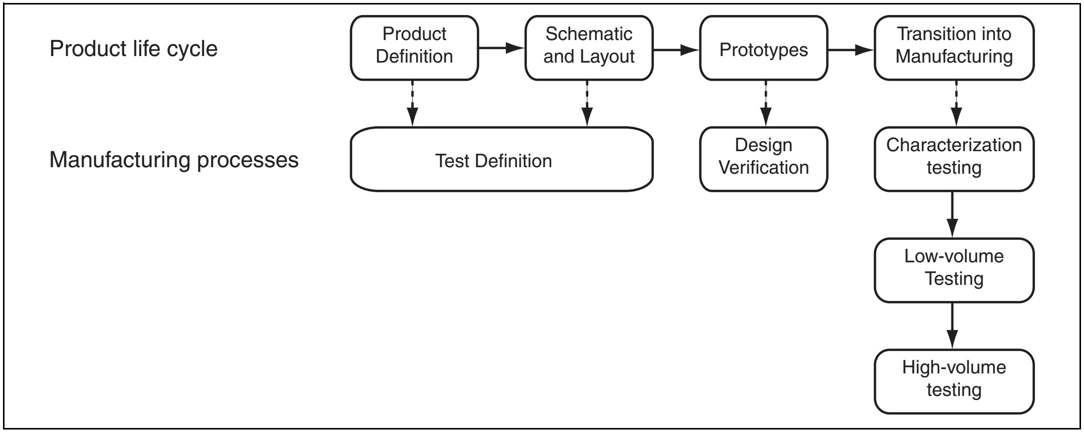
There are two primary objectives of PCB manufacturing testing:

- verify that components are placed properly on the boards,
- verify board functionality.

The overall goal is to maximize test coverage while minimizing test costs.

Manufacturing testing parallels the product lifecycle in that each phase is unique and builds on the previous phase. *Figure 1* shows the traditional product lifecycle and how the different phases of the manufacturing process align with it.

Figure 1. Product lifecycle



Four phases of testing products are recommended according to the product lifecycle. Each phase has a purpose and builds off the previous stages. The prototype phase is the first phase. The objective of this phase is to fully verify the design on a small number of devices. The characterization phase is next; this phase verifies the functionality of the product. Once the product has been fully characterized, volume testing is next. The two phases of volume manufacturing testing are low-volume and high-volume. The low-volume stage of testing is a subset of the characterization testing but with reduced test time and coverage. The high-volume stage of testing is a much faster test, which allows for ease of test and scalability. The objective of these manufacturing test phases is to verify that components are placed properly on the boards. The trade-offs discussed in these phases are the type of testing, test coverage, data collection, test application, test time, and test cost.

2.1 Phase I: prototype testing

The first phase of manufacturing tests involves initial prototype testing, also known as design verification/validation. This involves a product that has gone through its “first pass” on a new product introduction (NPI) assembly line. This phase incorporates bench tests with test equipment and usually is not automated. Prototype testing usually involves the design team. Therefore it is time consuming and expensive, but it is very important in verifying the product functionality.

Phase I trade-offs are as follows:

- Volume: First 5-50 boards
- Type of Testing: Bench test with test equipment, not automated
- Test Coverage: Full design verification
- Data Collection: Not automated but very detailed
- Test Application: Standalone application (for example, EmberZNEt's nodetest)
- Test Time: Large
- Test Cost: Expensive

This phase of testing will not be discussed in detail in this document.

2.2 Phase II: characterization testing

The second phase of testing in the product lifecycle is characterization testing. The objective of this phase is to verify functionality and repeatability. During this phase, the hardware is manufactured in higher volume (on an NPI line or production assembly line). The assembled product is fully characterized with automated test programs to determine design performance and manufacturability, as well as to collect valuable test data to be used to help with setting test limits in later phases. Typically, development and evaluation kits do not advance beyond this phase.

Phase II trade-offs are as follows:

- Volume: Next 500 to 1,000 boards, depending on the customer
- Type of Testing: Automated with test equipment
- Test Coverage: Full design verification
- Data Collection: Automated, datalogs
- Test Application: Standalone application or application test mode
- Test Time: 10-30 minutes per device
- Test Cost: Expensive

2.3 Phase III: low-volume manufacturing

The third phase is low-volume manufacturing. The objective of the volume manufacturing test phases (Phase III and IV) involves the verification of component placement. During this phase, a subset of the characterization testing may be performed. Test data from the characterization stage is used to help determine which tests may be reduced or eliminated. Test time during this stage is more important than the characterization stage because volumes are increased, but is still not crucial.

Phase III trade-offs are as follows:

- Volume: Next 1,000 boards
- Type of Testing: Automated with subset of test equipment
- Test Coverage: Subset of characterization tests
- Data Collection: Automated, datalogs
- Test Application: Standalone application or application test mode
- Test Time: 2-5 minutes per device
- Test Cost: Moderate

2.4 Phase IV: high-volume manufacturing

The fourth and final phase is high-volume manufacturing. During this phase, test time is crucial and only minimal testing may be required depending on the customer and the application. A Golden Node application (a known good device that can be used in test for repeatable measurements) can be developed to transmit and receive packets to and from a device under test to verify basic functionality. To further reduce test time, a manufacturing library can be used to allow for a test mode within the application itself, thus avoiding multiple programming steps.

Phase IV trade-offs are as follows:

- Volume: After 1,000 to 2,000 boards
- Type of Testing: Automated with subset of test equipment
- Test Coverage: Minimal, basic functionality
- Data Collection: Minimal data, still automated
- Test Application: Application test mode
- Test Time: Less than 1 minute per device
- Test Cost: Minimal

Note: An automated test is defined as a test method where test equipment and the Device Under Test (DUT) are controlled via a PC. A test program on the PC controls the test equipment and DUT. The DUT is loaded with embedded software that enables the radio to be configured for particular tests. This embedded software application could be a standalone test application or the customer's own application with a test mode included. A standalone application is provided, Nodetest, for customers to use. These applications are discussed in detail in the section "Embedded Software Tools."

Due to the different options available during Prototype Testing, this document focuses on the Characterization and Manufacturing Test phases (Phases II, III, and IV).

The following sections discuss RF testing and the testing of EmberZNet's products.

3 Test definitions

To communicate and control various test modes by automated test software, some software applications could be developed to allow for both serial communication as well as Over the Air (OTA) communication to automated test software. Both of these interfaces should enable configuring a device for receive or transmit modes, turning on peripherals (if applicable), reading Analog to Digital Conversion (ADC) pins on the micro (if applicable), putting the radio and/or microprocessor to sleep, and similar control functions.

The tests can be divided into different types of tests- RF testing, DC testing, and peripheral testing.

- RF testing is any test specific to the operation and functionality of the radio.
- DC testing is any test related to the voltage and current characteristics of the device or board.
- Peripheral testing is any test not specific to RF or DC, such as a sensor or an external crystal.

The following sections describe the tests that make up the potential suite of DUT testing.

3.1 Serial communication test

The Serial Communication Test verifies valid serial communication with the DUT prior to testing. This is a basic check that the device has been programmed correctly. If no communication is present, the DUT fails this test and does not proceed with further testing. This test is important because if there is no serial communication with the DUT, there is no way to interface with the DUT to put the device into test mode.

3.2 Channel calibration test

When a device is powered up for the first time and selects a channel, a calibration is automatically run to properly configure the device for operation. This calibration occurs the first time each channel is selected, as well as any time there is a change in temperature large enough to trigger recalibration.

Note: The hardware abstraction layer (HAL) in the embedded software controls the calibration.

It is recommended that customers select each channel so that the calibration is guaranteed to run prior to any functional testing. It is also recommended that the calibration data values be stored in a datalog or compared against a known range of valid values as a way of initially determining if there are any problems with the device or board. A check for valid calibration data can be a good initial test that the device is soldered down properly prior to any other functional checks.

The channel calibration data is stored within the token system. The calibration token is 64 bytes long, 4 bytes per channel:

- Byte 0: VCO at LNA cal; Reset = 0xFF, Minimum = 0, Maximum = 0x3F (6 bit)
- Byte 1: Modulation DAC; Reset = 0x80, Minimum = 0, Maximum = 0x3F (6 bit)
- Byte 2: Channel Filter; Reset = 0x80, Minimum = 0, Maximum = 0x1F (5 bit)
- Byte 3: Low Noise Amp; Reset = 0x80, Minimum = 0, Maximum = 0x3E (6 bit, LSB always 0)

For example, for the Modulation DAC (byte 1) anything above 0x3F is invalid with the exception of 0x80 which indicates that the channel has not yet been calibrated.

Any values equal to 0 or greater than or equal to the maximum value indicate a problem, so the acceptable ranges are as follows:

- Bytes 0,4,8,...,60: Values 0x01 to 0x3E are good, 0xFF is uncalibrated
- Bytes 1,5,9,...,61: Values 0x01 to 0x3E are good, 0x80 is uncalibrated
- Bytes 2,6,10,...,62: Values 0x01 to 0x1E are good, 0x80 is uncalibrated
- Bytes 3,7,11,...,63: Values 0x01 to 0x3D are good, 0x80 is uncalibrated

Note: *When programming a device for test or retest of a DUT, use the* `-erase` *option to ensure that all previous calibration data is erased. It is recommended erasing the flash contents of a device prior to testing to ensure the calibration is executed at the time the device is tested.*

3.3 Supply current test

The Supply Current Test verifies that current consumption is valid for each mode of operation for the DUT. The modes of operation are set via the serial interface and include transmit mode (multiple power levels, normal mode, and boost mode), receive mode (normal mode and boost mode), and sleep modes (radio sleep and deep sleep). If there is excessive current draw, the DUT fails this test and does not proceed with further testing. This test is especially important for devices that will be used in battery-operated applications, as these measurements are an effective predictor of battery life.

3.4 Quick verify of transmit and receive test

The Quick Verify of Transmit and Receive Test quickly verifies that the DUT transmits valid packets to the Reference Node and receives valid packets from the signal generator. This can be tested on any single channel in the available frequency band. If either of these checks fails, the DUT fails this test and does not proceed with further testing. This test identifies hardware that does not require full characterization testing due to a major manufacturing defect.

3.5 Transmit power test

The Transmit Power Test verifies that the power level of the transmitter is at the appropriate level and within a specified range. The power output is measured with the power meter at multiple power levels and in both normal and boost modes to confirm power output accuracy at various coded settings. The serial command interface can include a function that enables continuous waveform (CW) or unmodulated tone to be transmitted for ease of measuring these power levels. It is recommended that this test be performed over a subset of the frequency band to record trends in power output versus frequency.

3.6 Transmit frequency test

The Transmit Frequency Test verifies the crystal accuracy and valid transmission frequency of the DUT. The transmission frequency is measured with the frequency counter. The CW tone is again used for this transmission. It is recommended that this test be performed over a subset of the frequency band to record trends versus frequency.

3.7 Transmit error vector magnitude test

The Transmit Error Vector Magnitude (EVM) test verifies that the device's EVM is within specified limits. The EVM is measured with a spectrum analyzer. The transmit stream command used for this transmission and the spectrum itself is analyzed in this test. It is recommended that this test be performed over a subset of the frequency band to record trends versus frequency.

3.8 Transmit sweep test

The Transmit Sweep Test verifies transmission of valid packets from the DUT to the Reference Node for all channels or a subset of channels across the frequency band. The Reference Node is put into receive mode while the DUT transmits 100 packets to the Reference Node for each channel, with an attenuation between nodes that translates to a strong signal, approximately 60 dB attenuation between devices. Please refer to the specific radio chip datasheet for more information.

Packet success rate is measured for each channel. The packet success rate percentage is defined as the number of packets received divided by the number of packets transmitted and then multiplied by 100. For the Transmit Sweep Test, anything below 100% packet success rate is flagged as a failure, as this test is conducted at a signal level where all packets should be received. This test confirms that there are no frequency-dependent issues with transmit mode.

3.9 Receive sweep test

The Receive Sweep Test is similar to the Transmit Sweep Test. It verifies reception of valid packets at the DUT from the signal generator for all channels or a subset of channels across the frequency band and at two receiver input power levels (a strong signal level, approximately –50 dBm, and a level closer to the edge of sensitivity performance, approximately –90 dBm).

The DUT is put into receive mode while the signal generator transmits 100 packets for each channel. Packet success rate is measured for each channel/receive input level. Any packets missed at the strong signal level are considered a failure, while the failure threshold at the lower input level can be at a lower percentage, depending on the expected sensitivity of the radio. Please refer to the datasheet of the radio chip for details related to receive sensitivity. This test should be performed over the full operating band to record trends versus frequency.

3.10 Receive sensitivity test

The Receive Sensitivity Test determines the receiver sensitivity of the DUT. The DUT is placed in receive mode with 1,000 valid packets being sent from the signal generator for each channel. The power level should begin at some level prior to the 1% Packet Error Rate (PER) threshold. Please refer to the datasheet for the specific radio chip for more information on the sensitivity. The PER is measured until the receiver input power level corresponding to 1% PER is determined. This test should be performed over a subset of the operating band to record trends versus frequency. During the characterization testing phase it is recommended that the actual sensitivity level be determined, while at high volumes the receive sensitivity specification can be set as the low limit and be used as a single power level for ease of testing.

3.11 Receive drill-down test

The Receive Drill-Down Test determines the receiver sensitivity of the DUT by collecting data to determine the receiver roll-off curve. The DUT is placed in receive mode with 100 valid packets being sent from the signal generator for each channel. The power level should begin at some level prior to the 1% PER threshold. Please refer to the datasheet for the specific radio chip for more information on the sensitivity. The packet success rate is measured for all input powers selected for testing. It is recommended that enough input power levels are selected to ensure that the data collected includes both 100% and 0% packets received. This allows for a complete roll-off curve to be observed. This test should be performed over a subset of the operating band to record trends versus frequency. It is recommended this test for characterization testing so that the roll-off is quantified and understood but can be omitted at higher volumes.

3.12 Receive signal strength indicator (RSSI) test

The RSSI Test measures the RSSI value for a single channel and known receiver input power level. The RSSI is determined by receiving a valid packet from the signal generator and reading the RSSI value via the serial command interface. The DUT is placed into receive mode while the signal generator transmits a single packet and the RSSI measurement is averaged to determine RSSI value. This single data point is measured to verify that the RSSI pin for the radio chip is connected and that RSSI is reporting a valid level. The RSSI operation of the chip itself is validated at the chip testing level and is not tested here.

3.13 External 32-kHz crystal test

The operation of the external 32-kHz crystal (if applicable) should be verified.

3.14 Peripherals test

Various peripherals, if applicable, can be tested via the serial port. These include anything that may be accessed via the ADC or GPIO (general purpose I/O) on the micro. For example, an LED is often tied to a GPIO pin for some status to be alerted. The state of the LED can be modified by changing the level of the GPIO pin. Another example is reading an ADC pin for a particular voltage level that corresponds to the status of a peripheral such as a temperature sensor or an accelerometer. Any peripheral accessible via GPIO or the ADC should be tested to ensure valid functionality.

4 Test recommendations

This section outlines the various tests that can be run on the hardware product, and which tests are recommended to be run and the channel and power mode selection for each test in each phase.

4.1 Characterization testing

Characterization testing is recommended for early production stages. In this phase of testing, the hardware is characterized for all channels or a subset of channels, as well as at various receiver input power levels. This phase fully characterizes the hardware that is being developed, determines the tests to be executed in manufacturing tests, determines the test limits of these tests, and flushes out any manufacturing or process issues that might be present.

It is recommended that the tests outlined in *Table 1* be conducted in the characterization phase of testing. This table, and the similar tables that follow in subsequent sections of this document, list the various tests that could be run on these devices, which tests are recommended be run, and the channel and power mode selection for each test in each phase.

Note: An X in these tables represents a test that is recommended for this phase of testing.

Table 1. Characterization test recommendations

Test	**Run?**	**Channel**				**Power Mode**	
		Mid	**Low-Mid-High**	**Subset**	**All**	**Normal**	**Boost**
Serial Communication	X						
Channel Calibration	X				X		
Supply Current	X	X				X	X
Transmit/Receive Verify	X	X				X	
Transmit Power	X		X			X	X
Transmit Frequency	X		X			X	X
Transmit EVM	X		X			X	X
Transmit Sweep	X				X	X	
Receive Sweep	X				X	X	
Receive Sensitivity	X		X			X	X
Receive Drill-Down	X		X			X	X
RSSI	X	X				X	
External 32-kHz Crystal	X						
Peripherals	X						

4.2 Low-volume manufacturing test

Low-volume manufacturing test is usually a subset of the characterization testing. A subset of the channels or power levels can be tested to reduce the test time without compromising test coverage. For example, one channel/power level combination (likely mid-band at max power) can be measured for transmit power and frequency. Also, receive drill-down can be omitted and receive sensitivity can be run in its place, where a certain packet-success rate is expected at mid-band for a given input power level.

The results from the characterization phase of testing help determine not only what should be tested in the manufacturing phase but also the test limits to be applied to certain tests. For example, if a particular test does not fail at all during the characterization phase, it can be omitted from the manufacturing phase altogether. Also, if it is determined that a particular test will fail all channels if it fails at all, testing can be reduced from all channels to a single channel, most likely mid-band.

4.2.1 Test recommendations

Table 2 lists the tests recommended to be conducted in the low-volume manufacturing phase of testing.

Table 2. Low-volume manufacturing test recommendations

Test	Run?	Channel				Power Mode	
		Mid	Low-Mid-High	Subset	All	Normal	Boost
Serial Communication	X						
Channel Calibration	X				X		
Supply Current	X	X				X	X
Transmit/Receive Verify	X	X				X	
Transmit Power	X	X				X	
Transmit Frequency	X	X				X	
Transmit EVM							
Transmit Sweep	X			X		X	
Receive Sweep	X			X		X	
Receive Sensitivity	X	X				X	
Receive Drill-Down							
RSSI	X	X				X	
External 32kHz Crystal	X						
Peripherals	X						

4.2.2 Test times

The typical test time that can be achieved in the low-volume manufacturing test phase is three minutes per board. This assumes that approximately one minute of overall test time is allocated to programming the board and two minutes is allocated to actual testing. If the devices are preprogrammed, the overall test time can be reduced to approximately two minutes. Program times vary depending on the flash memory size of the microprocessor. Note that programming may be included at both the front end (test application) and back end (final application) of the process. If you do not want to perform multiple programming steps during this phase of testing, it is recommended that you include the manufacturing library in the final application.

4.2.3 Setting test limits

The results of the characterization phase of testing help determine how the limits are set for low-volume manufacturing tests. Other factors in setting limits are customer application and manufacturing variation. For example, if an application specifies only a certain amount of dynamic range, perhaps limits will be relaxed to allow for this. Manufacturing variation can also be a factor in setting limits. For example, if the performance of the board is sensitive to particular components, it is important to account for any performance variation that may be seen with these particular components.

4.2.4 Full characterization sampling

It is important to continue to fully characterize samples from each production run to ensure that nothing in the process has shifted, causing a difference in the overall performance of a production run compared to a previous run. The size of this sample can be determined by the manufacturer, but it is recommended this full characterization sampling for additional test coverage and process control at volume testing.

4.3 High-volume manufacturing test

High-volume manufacturing testing is much simpler than characterization testing or low-volume manufacturing testing. The hardware design and manufacturing process have already been proven, so the product now just requires a quick “go/no go” functional test to verify operation.

4.3.1 Test recommendations

It is recommended that the tests in *Table 3* be conducted in the high-volume phase of testing.

Table 3. High-volume test recommendations

Test	Run?	Channel				Power Mode	
		Mid	Low-Mid-High	Subset	All	Normal	Boost
Serial Communication	X						
Channel Calibration	X				X		
Supply Current	X	X				X	X
Transmit/Receive Verify	X	X				X	
Transmit Power							

Table 3. High-volume test recommendations (continued)

Test	Run?	Channel				Power Mode	
		Mid	Low-Mid-High	Subset	All	Normal	Boost
Transmit Frequency							
Transmit EVM							
Transmit Sweep							
Receive Sweep							
Receive Sensitivity	X	X				X	
Receive Drill-Down							
RSSI							
External 32kHz Crystal	X						
Peripherals	X						

4.3.2 Test times

The typical test time that can be achieved in the high-volume manufacturing test phase is less than one minute per board. This assumes that devices are preprogrammed with the customer application and that the customer application uses the manufacturing library for invoking test modes.

4.3.3 Setting test limits

Since the test environment in the high-volume manufacturing phase is different from the test environment in the low-volume phase, setting the limits is also done differently. The test limits for the basic transmit and receive tests are dependent on the fixed attenuation between the Golden Node and the DUT, as well as the variation in over-the-air results. It is recommended that customers run a sample size of boards through testing to determine these test limits.

4.3.4 Full characterization sampling

Even in high-volume testing, it makes sense to fully characterize samples from each production run to ensure that the process has not shifted in any way. The size of this sample can be determined by the manufacturer, but this full characterization sampling is recommended for additional test coverage at high volumes.

5 Test architecture and equipment

The following sections detail the recommended test architecture and equipment for each phase of testing, discuss test results and their dependence on test setup, and describe the typical manufacturing faults detected in manufacturing tests.

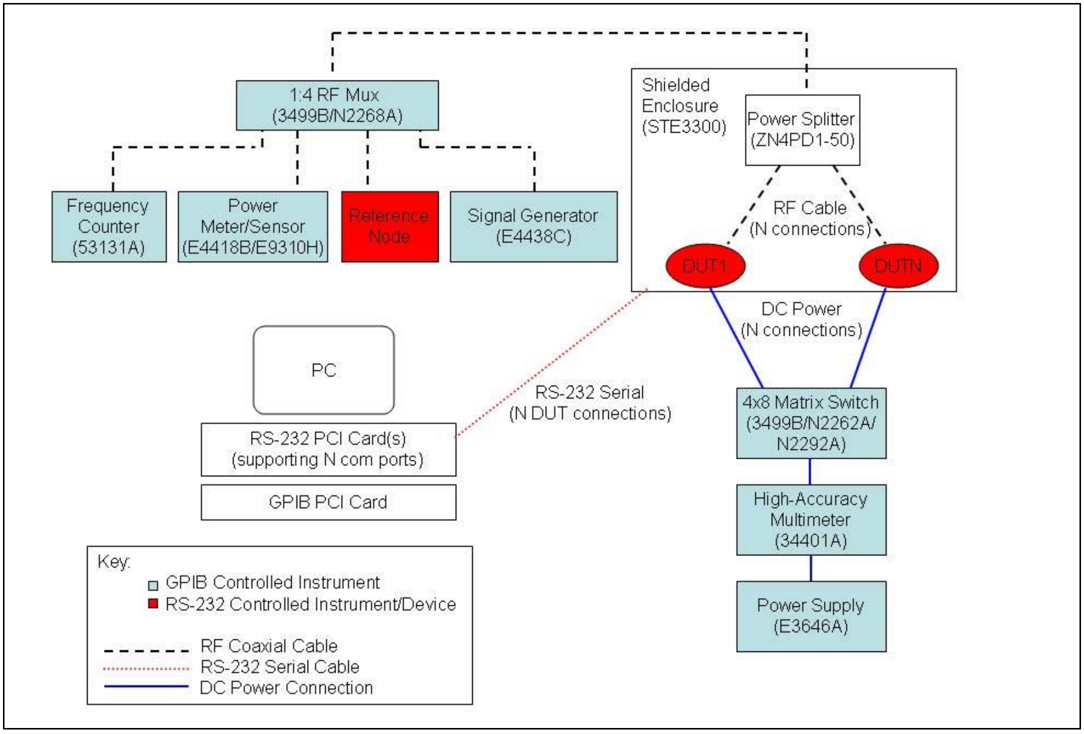
5.1 Characterization testing

The architecture and test equipment used in the characterization stage of testing is more comprehensive than that of the volume manufacturing stages.

5.1.1 Test architecture

Figure 2 shows an example of the interfaces of the test equipment with the DUT. The test equipment can be controlled by test software via the General Purpose Interface Bus (GPIB) or Recommended Standard 232 (RS-232). The DUT may be controlled via either RS-232,Virtual UART. Any number of DUTs may be tested at once, but this number is dependent on serial ports available and will affect the selection of the power splitter and matrix switch hardware described in *Figure 2*.

Figure 2. Example of a possible architecture of the characterization test



5.1.2 Recommended equipment

The recommended characterization test setup uses Agilent test equipment for the basic radio frequency (RF) measurements and current measurements, as well as for supplying power to the DUT and switching the RF connections from the DUT to various types of measurement equipment. A Reference Node, as mentioned in the characterization stage of testing, is any STM32W108 radio communication module (RCM) configured with the same radio chip as the DUT that can be used to verify transmission of packets from the DUT.

Table 4 lists the basic set of test equipment recommended for characterization testing.

Table 4. Recommended characterization test equipment

Manufacturer	Part Number	Description	Purpose
Agilent	E4418B	Power Meter	Used with power sensor to measure transmit power of the DUT
Agilent	E9301H	Power Sensor	Used with power meter to measure transmit power of the DUT
Agilent	53131A	Universal Counter	Measures the transmission frequency accuracy of the DUT
Agilent	53131A-030	3GHz Option	53131A universal counter option for 3GHz to measure the transmission frequency accuracy of the DUT
Agilent	E4402B	Spectrum Analyzer	Used to verify transmit power, transmit frequency accuracy, and EVM of the DUT
Agilent	89601A	Spectrum Analyzer VSA Software	Software option for the E4402B that allows for measuring EVM
Agilent	E4438C-504	Signal Generator - 250kHz to 4GHz	Verifies reception of valid packets at the DUT
Agilent	E4438C-1E5	Time Base Option	Improves frequency accuracy of E4438C
Agilent	E4438C-602	Baseband Generator	Internal baseband generator, 64MSa memory with digital bus capability
Agilent	E4438C-005	Hard Drive Option	6GB hard drive for E4438C
Agilent	E3646A	Dual Output Power Supply	Powers the DUT and Reference Node
Agilent	34401A	Digital Multimeter	Verifies current consumption of the DUT in various modes of operation
Agilent	3499B	Data Acquisition Switch Unit	Supplies power to the DUT and switches RF connection
Agilent	N2262A	4x8 Matrix Module	3499B module; supplies power to the DUT
Agilent	N2268A	3.5GHz 1:4 RF Mux Module	3499B module; switches RF connection from the DUT to the Reference Node, frequency counter, power meter, or signal generator
Agilent	N2292A	Screw Terminal Block	Terminal block accessory for N2262A 3499B module
Mini-Circuits	ZN4PD1-50	1:4 Multiplexer Splitter	Splits power from test equipment to a maximum of 4 DUTs; alternative parts can be used for more or fewer DUTs

Table 4. **Recommended characterization test equipment (continued)**

Manufacturer	Part Number	Description	Purpose
Ramsey Electronics	STE3300	Shielded RF Enclosure	Provides RF isolation for the DUT during testing
STM32W108	N/A	Reference Node	Known good radio module that is used as a receiver reference node in DUT transmit tests

Note: *It is recommended to use a spectrum analyzer and VSA software option for EVM testing and for general hardware debug. The spectrum analyzer may also be used in place of a power meter and frequency counter in characterization testing to measure transmit power and transmit frequency offset. In volume manufacturing tests, however, the power meter and frequency counter are a much more cost-effective method of measuring transmit power and transmit frequency offset than the spectrum analyzer.*

5.1.3 Configuring equipment

Some test equipment needs to be configured specifically for 802.15.4 radio communications. For the signal generator, for instance, the specific packet needs to be configured.

5.1.4 Low-cost alternative to signal generator (Golden Node)

For some customers, adding a signal generator to manufacturing tests is not desired or not possible due to cost concerns. In this case, it is recommended using a Golden Node (a known good device that can be used in test for repeatable measurements) with TCXO (temperature controlled/compensated crystal oscillator). The TCXO allows for frequency accuracy when using the Golden Node as a known good transmitter source for DUT receive tests. Using a Golden Node without TCXO would present issues with test accuracy, as the crystal would drift over time and temperature. The Golden Node will have known transmitter performance (0 dBm ± 0.5 dBm) across voltage and temperature, allowing for test repeatability.

5.1.5 RF test interface examples

The type of interface to the DUT and the RF shielded test enclosure selected for testing can determine the accuracy and repeatability of the measurements. The Ramsey STE3300 test enclosure listed in *Table 4* is recommended.

It is important to pay special attention to the RF test interface with the DUT because of the sensitivity of these signals. For example, a product with a 50-Ohm terminated Subminiature Type A (SMA) connector populated on the board can be connected directly to a coaxial cable with a known loss. Repeatability in this scenario is very good.

Another example is a product with an embedded antenna that was designed with test points for RF and ground can be connected with a pogo-pin style RF probe. The path loss from the RF test point to the cabled connections of the setup can be calibrated to determine accurate performance. The repeatability of this setup is dependent on the board layout, in the sense that the RF and ground signals should have test points in close proximity to one another. The repeatability is also more dependent on the shielded enclosure in this case, because the RF signal is exposed at the test point rather than enclosed within an SMA connector as in the first example.

As a final example, a product with an embedded antenna can be tested over the air within an enclosure. A reference antenna would be used within the enclosure to feed back the RF signal to the RF Mux. The path loss over the air from the reference antenna to the DUT antenna can be calibrated to determine accurate performance. Fixed position of the DUT and position of the DUT and reference antennas are crucial to getting repeatable results.

5.2 Low-volume manufacturing testing

The architecture and test equipment used in the characterization stage of testing is more comprehensive than that of the volume manufacturing stages.

5.2.1 Test architecture

The test architecture in the low-volume phase of testing is very similar to that of the characterization phase.

5.2.2 Recommended equipment

The equipment it is recommended for the low-volume manufacturing phase of testing is very similar to that for the characterization phase. Some of the equipment may be removed depending on the tests selected for this phase.

5.2.3 Interference

There are many RF devices in a test environment, such as wireless networks, microwave ovens, and mobile phones. For this reason, it is important to maintain RF isolation of the DUT from these sources of interference. It is also important to maintain RF isolation between multiple stations. For example, the equipment for test station A should be able to communicate only with a DUT from test station A and not with a DUT from test station B. Likewise, the equipment for test station B should be able to communicate only with a DUT from test station B and not a DUT from test station A. If these stations are not isolated from each other, the DUT will not be uniquely configured and multiple boards could share unique configuration information.

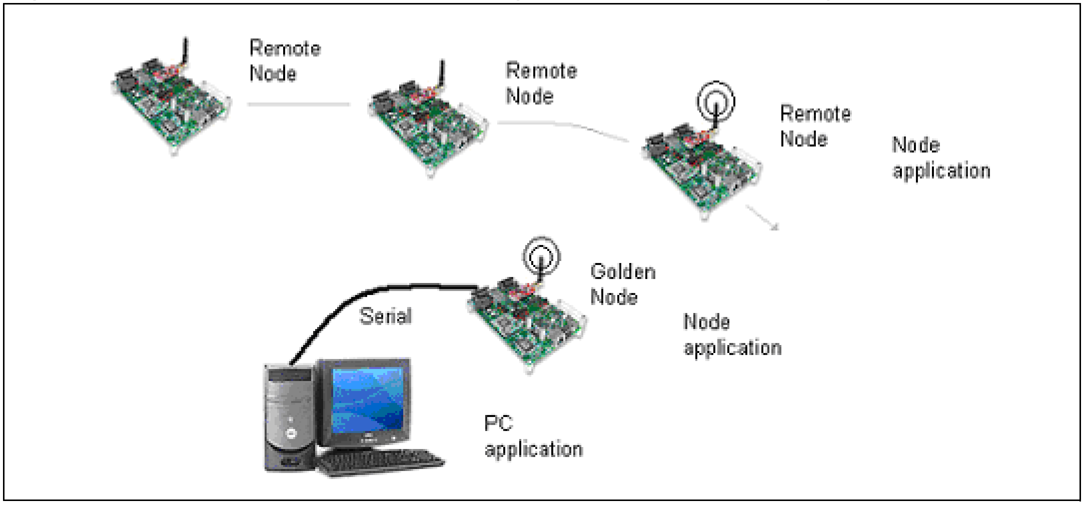
5.3 High-volume manufacturing testing

The architecture and test equipment used in the characterization stage of testing is more comprehensive than that of the volume manufacturing phases.

5.3.1 Test architecture

The test architecture in the high-volume phase of testing can be structured any number of ways depending on customer preference. One approach is to develop this test with a Golden Node programmed with an application that allows the DUT to obtain unique configuration information from the Golden Node via packets transmitted and received. This test may be limited to configuring one DUT at a time. The Golden Node initiates communication with the unconfigured DUT and sends unique configuration information to the DUT. The Golden Node can then interface with the PC application to configure the DUT uniquely. Then the DUT can reboot itself and be ready for testing or application operation. A basic transmit/receive test can then be run. The test architecture for this phase of testing is shown in *Figure 3*.

Figure 3. Architecture example of a high-volume manufacturing test



Another approach is to develop a test with a serial interface to both the Golden Node and the DUT. This may be more straightforward to develop but requires a more extensive set up and use of a UART.

5.3.2 Recommended equipment

The equipment is based on the tests selected for this phase of testing, as well as the preference of the customer. No matter the approach, it is important that at the very least the Golden Node (and in some cases the DUT) have an interface to a PC or server so that it can log test information such as calibration data, serial numbers, EUI, test results, and so on.

5.3.3 Interference

A facility running multiple test stations maintains RF isolation among the stations, as previously detailed. In this test phase, the only interface to the DUT is power, as all communication between the Golden Node and the DUT is done via the radio. All of the test equipment used in the characterization testing can be removed from the process, unless a customer decides to continue to test certain functionality on the board that requires test equipment.

5.4 Manufacturing coverage

Manufacturing testing not only determines the tests that should be included in the manufacturing test phase, but it also helps detect manufacturing failures. The following sections provide some examples of typical manufacturing faults and how they are detected in testing.

5.4.1 Excess solder on STM32W108

An excess amount of solder will result in any number of failures in test. Excess solder will cause coplanarity issues and prevent some pins on the device from making contact with the pads on the board, as well as cause shorting of pins. This will likely result in programming failures, serial communication failures, and RF performance problems, all of which are detected in manufacturing tests.

5.4.2 Insufficient solder on STM32W108

An insufficient amount of solder will result in any number of failures in test. Insufficient solder will prevent some pins on the device from making contact with the pads on the board. This will result in programming failures, serial communication failures, and RF performance problems, all of which are detected in manufacturing tests. Insufficient solder on the ground pad underneath the device will result in degraded RF performance, most likely in the receiver. This type of issue will be detected in either the Receive Drill-Down Test or Receive Sensitivity Test. In some drastic cases where there is no solder on the ground pad and thus no ground connection from the device to the board, the device will not function and would either fail to program or fail to calibrate properly.

5.4.3 Incorrect component

An incorrect component or component value will alter the performance of the board. For example, if a crystal tuning cap is the incorrect value, the Transmit Frequency Test will detect this failure because the frequency will be outside the specified limits. If a component in the matching network is incorrect, this will affect the transmit power and will be detected in the Transmit Power Test. If a decoupling capacitor is the wrong value, it will affect the receiver performance of the device and will be detected in either the Receive Drill-Down Test or the Receive Sensitivity Test.

5.4.4 Missing component

A missing component will also alter the performance of the board. For example, if there is a component missing from the RF path, there will be a major degradation in the transmit output power and overall receive sensitivity of the board. Also, if a component is missing that affects power distributed to the microprocessor or radio chips, the board will not be able to communicate serially in the case of the micro; the microprocessor will not configure the radio to transmit or receive in the case of the radio. The Component Removal Study section presents details for the affects of missing components on board performance as it pertains to manufacturing tests.

5.4.5 Solder shorts or opens

A solder short or open on any component or device will cause any number of failures in manufacturing tests. Any short or open in the RF circuitry of the board will cause degradation in performance and will be detected in various RF tests. A short or open in the DC circuitry or programming circuitry will prevent the device from programming properly and/or communicate properly with the test interface. For all of these cases mentioned, at least one test will detect a failure and flag this device as defective.

6 Embedded software tools

Two different embedded software tools are supported for manufacturing tests: a standalone test application called Nodetest, and a manufacturing test library that is used as a test mode within the customer application. The following sections describe these two embedded software tools.

6.1 Standalone test application - Nodetest

The characterization stage typically utilizes a standalone test application. Nodetest is a standalone test application that is recommended for any test stage in which the customer's application is not yet mature enough to include a test mode. Nodetest provides a serial command line interface to the STM32W108 device.

Note: The Nodetest files can be found in the stack installer at /app/nodetest/.

6.1.1 Nodetest commands

The Nodetest application runs the serial port at 115200 for the STM32W108, so be sure that your baud rate has been set accordingly. A carriage return initiates the Nodetest application on reset or power-up. This displays the power-up prompt, which ends with the `>` (greater than) symbol. *Table 5* lists some of the nodetest commands.

Table 5. Nodetest commands

Command	Description
`?, help`	Prints the Help menu.
`calChannel`	Use `calChannel x` to switch to channel x and perform calibration. (Uses current channel if x is not specified.)
`setChannel`	Sets the channel (11 by default). For valid values, see the device's technical specification.
`ledoff`	Use `ledoff x` to turn BOARDLEDx off.
`ledon`	Use `ledon x` to turn BOARDLEDx on.
`ledToggle`	Use `ledToggle x` to toggle BOARDLEDx.
`rx`	Puts the device into receive (RX) mode on the current channel.
`shutdown`	Use `shutdown` to put the device into deep sleep mode.
`tokdump`	Dumps all known tokens and their values.
`tokread`	`tokread <key>` shows the contents of the token indexed by <key> as the stack will read it when run.
`tokwrite`	`tokwrite <key>` writes a new value to the token indexed by <key> and prompts for each byte of data. Manufacturing tokens cannot be written with this command.
`tx`	Transmits the specified number of packets on the current channel (infinite if 0).
`setTxPower`	Sets power to specified dBm. For valid values, see the device's technical specification.

Table 5. Nodetest commands (continued)

Command	Description
`setTxPowMode`	Use `setTxPowMode x y` for x = 0 or 1 and y = 0 or 1 to engage Boost mode (x = 1) for the chip or switch to using the external PA (RF_TX_ALT_P/N) signal path (y=1).
`txstream`	Performs a modulated carrier wave transmission on the current channel.
`txtone`	Performs an unmodulated carrier wave (“tone”) transmission on the current channel.

6.2 Application test mode - manufacturing test library

It is recommended using the manufacturing test library for customers who are using mature applications, regardless of the testing phase. However, this library is typically used in the low-volume and high-volume phases of testing where additional programming steps add unnecessary test time. This library allows for accessibility to a test mode within the customer's application and removes the need for multiple application bootloads or multiple programming steps within the manufacturing process. There is a sample application (mfg-sample) available that demonstrates the use of this library. The following sections detail this manufacturing library.

Note: The manufacturing library files can be found in the stack installer at /app/mfglib

6.2.1 Use cases

This library can optionally be compiled into the customer's production code and run at manufacturing time. The application handles any interface to the library. This library cannot assist in hardware start up.

6.2.2 Use overview

The manufacturing library provides APIs to relevant nodetest functions that the customer application may call. The APIs provide a reporting mechanism that can give the customer application whatever information is required to report the information back to the manufacturing test equipment. Unlike nodetest, each routine in the manufacturing library returns a status value of some sort, and provides for output arguments or callback functions that, if specified, will be filled in or called with relevant information. The library is not concerned with the actual reporting of the information. This is application specific, and can be handled at the application layer. Customers can access this library over many ports and protocols.

The sample application mfg-sample provides an example of how to access this library over the serial port of the STM32W108.

6.2.3 General functions

The manufacturing library includes the functions that do the work and return the results and `status`. Customers can see how these functions are used or called by referencing the sample application. Customers only need to type the command over the correct port. The specifications for the manufacturing library APIs are detailed in the EmberZNet Unified API Reference document for the STM32W108.

The section that details the manufacturing library APIs is Module Index, subsection EmberZNet Stack API Reference, and subsection Manufacturing and Functional Test Library.

6.2.4 Code size

There a commitment to keeping the manufacturing library as small as possible.

6.2.5 Sample application functions

The sample application mfg-sample enables this functionality via a serial command interpreter. The command interpreter is realized in the sample application. The command interpreter is serially driven. *Table 6* lists the format of these commands related to these manufacturing library APIs.

Table 6. Sample application commands

Command	Description
`MFG`	Prints list of mfg commands.
`MFG START <want_callback>`	Shows how to use `mfglibStart()` to start use of `mfglib` test functionality and packet receive functionality. Receive handler callback is 0 for false, 1 for true.
`MFG END`	Shows how to use `mfglibStop()` to end use of `mfglib` test functionality.
`MFG TONE <[START][STOP]>`	Shows how to use `mfglibStartTone()` and `mfglibStopTone()` to transmit a tone over a radio.
`MFG STREAM <[START][STOP]>`	Shows how to use `mfglibStartStream()` and `mfglibStopStream()` to transmit a stream of random characters over a radio.
`MFG SEND <numPackets> test-packet <length>`	Shows how to use `mfglibSend()` to send a packet of (length) bytes of the test-packet payload (`numPackets`) times.
`MFG SEND <numPackets> random <length>`	Shows how to use `mfglibSend()` to send a packet of (length) bytes of a random payload (`numPackets`) times.
`MFG SEND <numPackets> message <first 8 bytes> <second 8 bytes>`	Shows how to use `mfglibSend()` to send packets of specified payload (`numPackets`) times.
`MFG CHANNEL SET <channel>`	Shows how to use `mfglibSetChannel()` to set the radio channel.
`MFG CHANNEL GET`	Shows how to use `mfglibGetChannel()` to get the radio channel.
`MFG POWER SET <power>`	Shows how to use `mfglibSetPower()` to set the radio transmit power level.
`MFG POWER GET`	Shows how to use `mfglibGetPower()` to get the radio transmit power level.

6.2.6 Demonstration of non-library features

In addition to the RF-related features, the sample application mfg-sample demonstrates network features. *Table 7* lists and describes the features of the reference application.

Table 7. Non-library features

Feature	Description
Network functions	A way for the sample application to perform network join and form functions.

The sample application includes additional non-library commands to demonstrate these features, many of which already have hal, token, or stack support which will be exploited by the sample application.

Table 8 lists and describes the non-library feature commands.

Table 8. Non-library feature commands

Command	Description
`HELP`	Prints the Help menu list of commands.
`VERSION`	Prints the mfg-sample version number information.
`INFO`	Prints various information about the device and device status, including app version, network status, EUI-64 of device, mfg mode status, and stack status.
`NETWORK`	Prints the network help menu list of commands.
`NETWORK FORM <channel> <power> <panid in hex>`	Command for forming a network with channel and power settings for a particular `panid` in hexadecimal format.
`NETWORK JOIN <channel> <power> <panid in hex>`	Command for joining a network with channel and power settings for a particular `panid` in hexadecimal format.
`NETWORK INIT`	Command for initializing a network.
`NETWORK LEAVE`	Command for leaving a network.
`NETWORK PJOIN <time>`	Command for permitting joining a network for a period of time (in seconds).
`RESET`	Resets the device.

7 Conclusions and summary

As you can see from the descriptions of each test phase within this document, the recommended tests and test flow are different when comparing characterization testing with manufacturing testing. Table 9 lists the test recommendations by phase and Table 10 compares the test phases.

Note: *In Table 9, C denotes tests recommended for characterization testing, L denotes tests recommended for low-volume manufacturing testing, and H denotes tests recommended for high-volume manufacturing.*

Table 9. Test recommendations by phase

Test	Run?	Channel				Power Mode	
		Mid	Low-Mid-High	Subset	All	Normal	Boost
Serial Communication	CLH						
Channel Calibration	CLH				CLH		
Supply Current	CLH	CLH				CLH	CLH
Transmit/Receive Verify	CLH	CLH				CLH	
Transmit Power	CL	L	C			CL	C
Transmit Frequency	CL	L	C			CL	C
Transmit EVM	C		C			C	C
Transmit Sweep	CL			L	C	CL	
Receive Sweep	CL			L	C	CL	
Receive Sensitivity	CLH	LH	C			CLH	C
Receive Drill-Down	C		C			C	C
RSSI	CL	CL				CL	
External 32kHz Crystal	CLH						
Peripherals	CLH						

Table 10. Comparison of test phases

Step	Characterization	Manufacturing Low-Volume	Manufacturing High-Volume
Program bootloader (if applicable)	Functional Test	Functional Test or Preconfigured	Preconfigured
Program/load test application	Functional Test	Functional Test or Preconfigured	Manufacturing library within final application
Load stack information	Functional Test	Functional Test or Preconfigured	Preconfigured
Load manufacturing Information	Functional Test	Functional Test	Golden Node application

Table 10. Comparison of test phases (continued)

Step	Characterization	Manufacturing Low-Volume	Manufacturing High-Volume
Load application information	Functional Test	Functional Test	Preconfigured
Verify DUT operation	Functional Test	Functional Test	Golden Node application
Program/load production application	Functional Test	Functional Test	Preconfigured

In the characterization phase of testing, all test steps can be automated to occur within the test itself. In the low-volume manufacturing phase, some of these steps can be performed before actual manufacturing. For example, the device can be preconfigured with the appropriate bootloader and/or test application. In the case of high-volume manufacturing, the test functions can be included in the production application as a test mode, as previously mentioned with the manufacturing library. The Golden Node application can be developed by the customer to configure the appropriate unique manufacturing information for each DUT.

8 Revision history

Table 11. Document revision history

Date	Revision	Changes
08-Apr-2010	1	Initial release.

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