

Final Test Considerations for Wireless Technology Products

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ABSTRACT

This application note highlights suggested best practices to be adopted in manufacturing the low-power radio frequency (LPRF) enabled devices. TI provides many software and hardware application development tools which can be effectively and efficiently used to realize a semi-automated production line setup for LPRF-enabled devices.

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1 Introduction

Low-power wireless radio technology is an important application to many products where wireless connectivity is needed. But the world of RF is completely different from the conventional development environment perspective, as the frequencies involved make the testing of such systems more complex. TI has a huge portfolio of low-power wireless SimpleLink™ solutions catering to the frequency band from 169 MHz in sub-GHz band through the 2.4-GHz band. Each device in the portfolio has exhaustive reference design data and guidelines on layout of the board around the chip, for fast and easy development. The RF performance observed during the application development is attained with expensive lab equipment (spectrum analyzers, network analyzers, and so forth) which may not be possible to put in the production line, thereby generating the need to come up with alternative solutions to solve the quality requirements of the final product.

This document covers the guidelines for implementing a high volume production test of products enabled by low-power wireless technologies. The need to achieve maximum yield with best possible quality generates a requirement to make an inexpensive, yet reliable test methodology. This document also covers suggestions to make the testing and production as automated as possible to eliminate the likelihood of manual errors.

2 Module Manufacturing

One thing needs to be clearly understood and kept in mind that the RF performance of any low-power wireless device depends not only on the actual silicon device but also on its basic building blocks, which are the discrete component (value, tolerance, package) or the PCB (material, thickness, layout). Any deviation on the critical components can result in reduced performance or out of band signal noise issues.

2.1 PCB Material Selection

When selecting the base material for a product, there is a tradeoff between price, safety and performance. FR-4 glass epoxy has proven, over time, to be a versatile product that has the best compromise between price and safety while exhibiting acceptable RF performance. There are numerous PCB materials that have better RF performance and similar safety specifications but come with a much higher price tag.

Not all FR-4-compliant materials are made the same and typically the differences are exposed at higher frequencies first, so it is highly recommended placing requirements on the PCB manufacture to not change FR-4 vendor without prior approval.

2.2 PCB Thickness and Stack Profile

The PCB thickness and stack up are critical in attaining the desired performance and must be strictly followed. A slight variation in the PCB profile can lead to unaccounted changes in impedance which in some cases can cause significant performance degradation.

The thickness of the PCB should not be more than 1.0 mm for 2-layer and 1.6 mm for a 4-layer PCB. For multilayer boards, the top layer should be less than 1.0 mm. *In general, the thinner the active RF layer is, the better the performance is, however, the mechanical integrity of the design must also be considered.* Most of the TI reference designs clearly mention the stack profile for the designed board.

2.3 Copper Mask Thickness

The final copper thickness on the outer layers of a PCB is determined by two variables:

- First is the initial copper thickness, this is the thickness of the copper foil used during the assembly of the PCB stack up. The most common thickness is 1-oz copper which stands for 1 oz of copper per square foot, resulting in a copper thickness of 30 μm .
- Second, the thickness of the copper plating added during the process used to create the via's needed to connect the various conductor layers of the PCB. The most common thickness again, is 1-oz copper per square foot, or 30- μm copper thickness.

The thicker the conductor, the more current the conductor can carry. Sometimes the final copper thickness is greater than 60 μm . For RF circuits this is generally not advisable because the resolution of the line etching process is reduced as the copper thickness is increased, resulting in poor tolerance of RF lines' characteristic impedance.

2.4 DC Check

Implement DC checks at various spots in the production flow to be able to catch production issues before the assemblies are fully populated and the cost of rejecting is increased.

Implementing a comprehensive DC shorting test on the bare PCBs is a cost-effective method of rejecting PCB-only manufacturing issues that could have resulted in costly final unit test yield.

2.5 Solder Masking

Solder mask is an essential and important part in the board fabrication. Solder mask in the RF section is critical, for example, to avoid unintentional shorting due to solder debris. Solder mask in the antenna feed point can be skipped.

2.6 Bill of Material (BOM)

Each component in the BOM for the low-power wireless radio device is a tested and calculated component. Do not deviate from the manufacturer, the value, and the source of the component. If, during the product life cycle, it becomes required to change a particular component then the entire cycle of testing needs to be carried out, involving the output power optimization, frequency stability (over temperature range), out of band transmission, harmonic levels.

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2.7 Cleanliness

Avoid using flux. The conductive nature of flux may lead to shorting or variation of RF performance in the radio device. *After assembly, clean the module with IP (isopropyl alcohol) or aqueous wash and then properly dry the module.*

2.8 High Temperature Solder

If the device has to be mounted on a motherboard using the reflow process, then the solder for the sub-module has to be high-temperature grade as the reflow may lead to de-soldering or opening of component solder joints.

2.9 Shielding Material

For the different certifications and wireless planning compliance, usually a shield on the board is required to confine the unwanted spurs and harmonics in and out of band. Common shielding materials are tin, nickel-silver alloy, nickel-brass alloy or treated oxidized copper. Another important point is soldering, as an improper soldering technique can defeat the entire purpose of having the shield. The sides of the shield must be soldered with no gaps on the corners. Place vias on the edges of the shield to connect to the ground. Gaps should be less than 1/10 of a wavelength (λ) of the fifth harmonics wave (approximately 2 mm).

3 Module Testing at the Manufacturing Line

Testing the board or module for the desired performance is the most critical and important procedure in the manufacturing line. This section highlights several items on the module that should be automatically checked at selected test points. The following section lists some of the most important tests:

3.1 Things to be Tested/Scoped

1. Output power test
2. Frequency offset test
3. RX sensitivity
4. Current consumption of the module.
 - (a) During TX
 - (b) During RX
 - (c) During Sleep

3.2 Radio Registers to be Used for Testing

There are specific registers in TI radios which need to be used for the module performance judgment. The interpretation of the RSSI, FREQEST, and FREQTUNE registers which is used for testing and calibration purposes is described in [Section 3.2.1](#) through [Section 3.2.3](#).

3.2.1 Register for Frequency Error Value

The frequency error is calculated and updated in the specific register of the CC radio. For example, the CC112x, which is a sub 1-GHz transceiver, the **FREQOFF_EST-0/1**, register gives you the Frequency Offset Estimation in 2's complement format.

Similarly, using CC253x/4x, the SOC's **FREQEST** register gives the Frequency Offset Estimation.

3.2.2 Register for Frequency Error Correction

The generated VCO frequency is configured through register **FREQ-0/1/2**. There is a provision in the TI CC radios to perform the OFFSET correction/calibration using the Frequency Estimation Register output.

For example, in the CC112x, the **FREQOFF-0/1** register is used for the correction of offset. This register value can either be manually fed or can be programmed automatically to be updated by enabling the bit in **FREQOFF_CFG, that is OR it with 0x30**).

Similarly, in the CC253x/4x, the **FREQTUNE** register needs to be loaded as per the offset of the frequency.

3.2.3 Register for Measurement and Testing

For RX and TX performance of the radio, RSSI and TXPOWER are the parameters to be measured and scoped.

Each TI CC radio has an RSSI register, giving the strength of the received signal at the configured frequency band. For example, with the CC112x, RSSI is a 12 bits two's complement number with 0.0625 dB resolution, hence ranging from -128 to 127 dBm. A value of -128 dBm indicates that the RSSI is invalid.

As an example, assume a -70 dBm signal into the antenna and $\text{RSSI}[11:0] = 0x200$ (32) when $\text{AGC_GAIN_ADJUST.GAIN_ADJUSTMENT} = 0x00$. This means that the offset is 102 dB as $32 \text{ dBm} - 102 \text{ dB} = -70 \text{ dBm}$.

Similarly, for the CC253x/4x, the RSSI value is a 2's-complement signed number on a logarithmic scale with 1-dB steps. To find the actual signal power (P) at the RF pins with reasonable accuracy, an offset must be added to the RSSI value.

$$P = \text{RSSI} - \text{OFFSET} [\text{dBm}]$$

For example, with an offset of 73 dB, reading an RSSI value of -10 from the RSSI register means that the RF input power is approximately -83 dBm.

The output power of the radio needs to be configured as per the application need and can be done through a register.

For example, in the CC112x, the output power of the radio is configured and controlled through the **PA_CFG0/1/2** register. The resolution of the output power is up to 0.5 db. When used along with the range extended or additional power amplifier, the register needs to have the value loaded accordingly. Also with PA in front, the port configuration also needs to be updated for enable and disable of the PA and LNA for TX and RX, respectively.

Similarly, in the CC253x/254x, the TXPOWER register is used to control the output power of the radio. When used along with the range extended or additional power amplifier, the register value remains the same but the port register (P0/1) value takes care of enable and disable of the PA and LNA for TX and RX, respectively.

Conclusively, the TI radio allows creation of a cost friendly, easy to use and maintain, semi-automatic production test and quality control setup with the inbuilt capabilities and featured data registers.

3.3 Probable Reasons for Variations in Test Points

This section provides the most probable reasons for variations in the test points listed in [Section 3.1](#).

1. Variation in R/C/L components. Swapping of the components or different values.
2. Crystal variation due to different make and loading capacitance.
3. Dry soldering or cold solder points.
4. Various PCB manufacturing issues not found during the DC short check.

4 Recommended/Suggested Test Procedure

In [Figure 1](#), the test setup and its essential components (devices) are shown along with DUT (device under test).

4.1 Setup 1

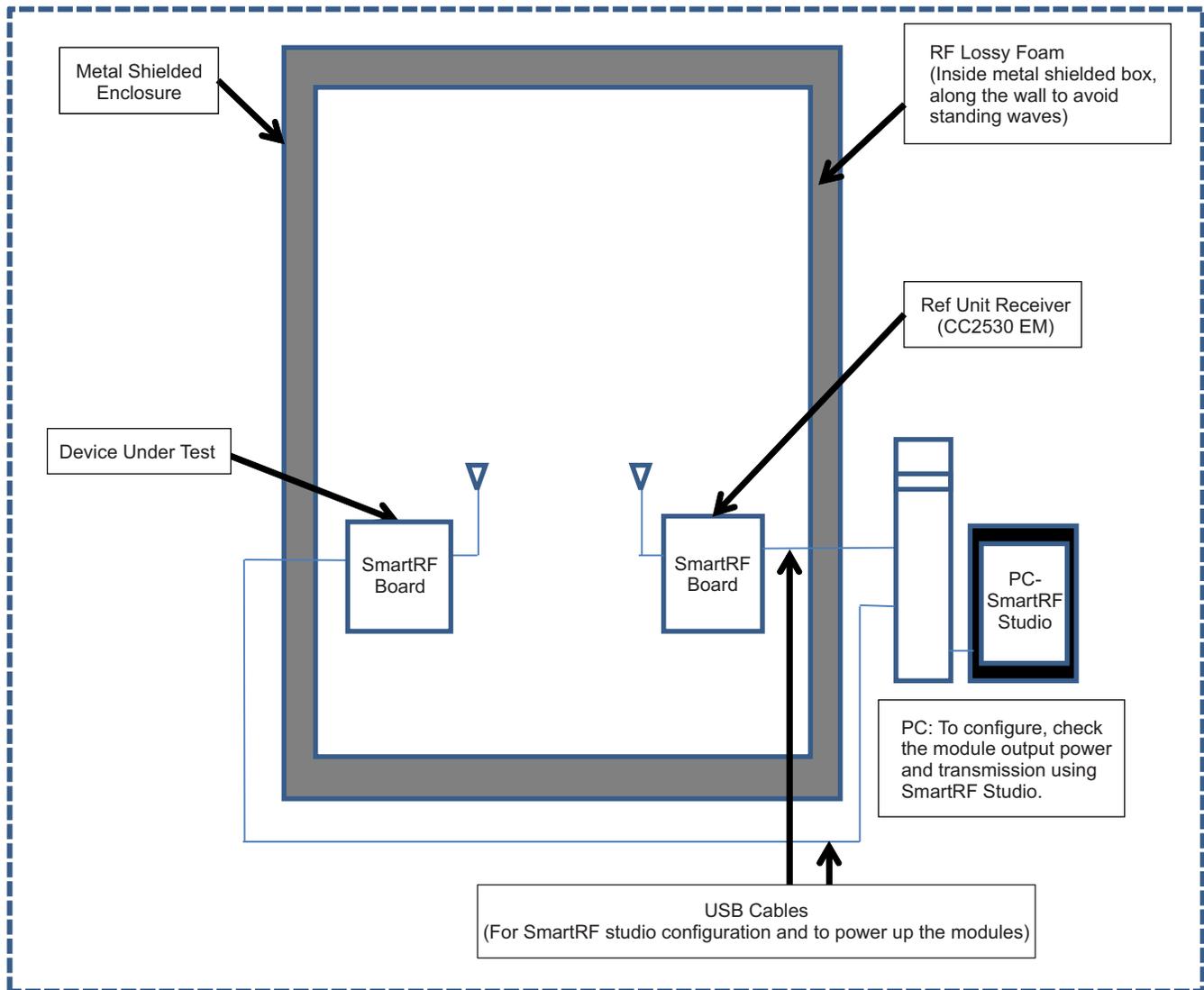


Figure 1. Suggestion 1: Setup Used in Production Line

4.1.1 Procedure for Setup-1

1. Output Power Test
 - (a) Using SmartRF studio, configure the DUT in Continuous modulated transmission (any fixed channel).
 - (b) Put the Reference receiver in Continuous Receiving (same channel as transmitter).
 - (c) Check the graph and peak on PC.
2. Frequency Offset
 - (a) Using SmartRF studio, put the DUT in Continuous Receiving mode.
 - (b) Put the Reference (TI EM) in continuous transmission.
 - (c) Read and log the RSSI OFFSET on SmartRF studio. This is a reference for all the modules.
 - (d) Put DUT in continuous transmission and Reference (TI EM) in continuous Receiving mode.
 - (e) Read the RSSI OFFSET on SmartRF studio, match it to the logged value.
3. RX Sensitivity
 - (a) Using SmartRF studio, configure the DUT in Continuous Receiving (any fixed channel).
 - (b) Put the Reference (TI EM) in Continuous Transmission (same channel as Receiver). Ensure TX power of maximum level.
 - (c) Check the graph on DUT on PC for receiving signal.
4. Current Consumption
 - (a) Measure the current consumption (putting multimeter in series on connector at SmartRF board) with the DUT in previously completed tests and match it to the following (or the reference module tested thoroughly in your lab):
 - (i) Full power TX: In milliamps as per the configuration of with/without PA.
 - (ii) RX mode: In milliamps
 - (iii) Sleep/Idle Mode: In milliamps

4.2 Setup 2

In Figure 2, the test setup and its essential components (devices) are shown along with DUT (device under test).

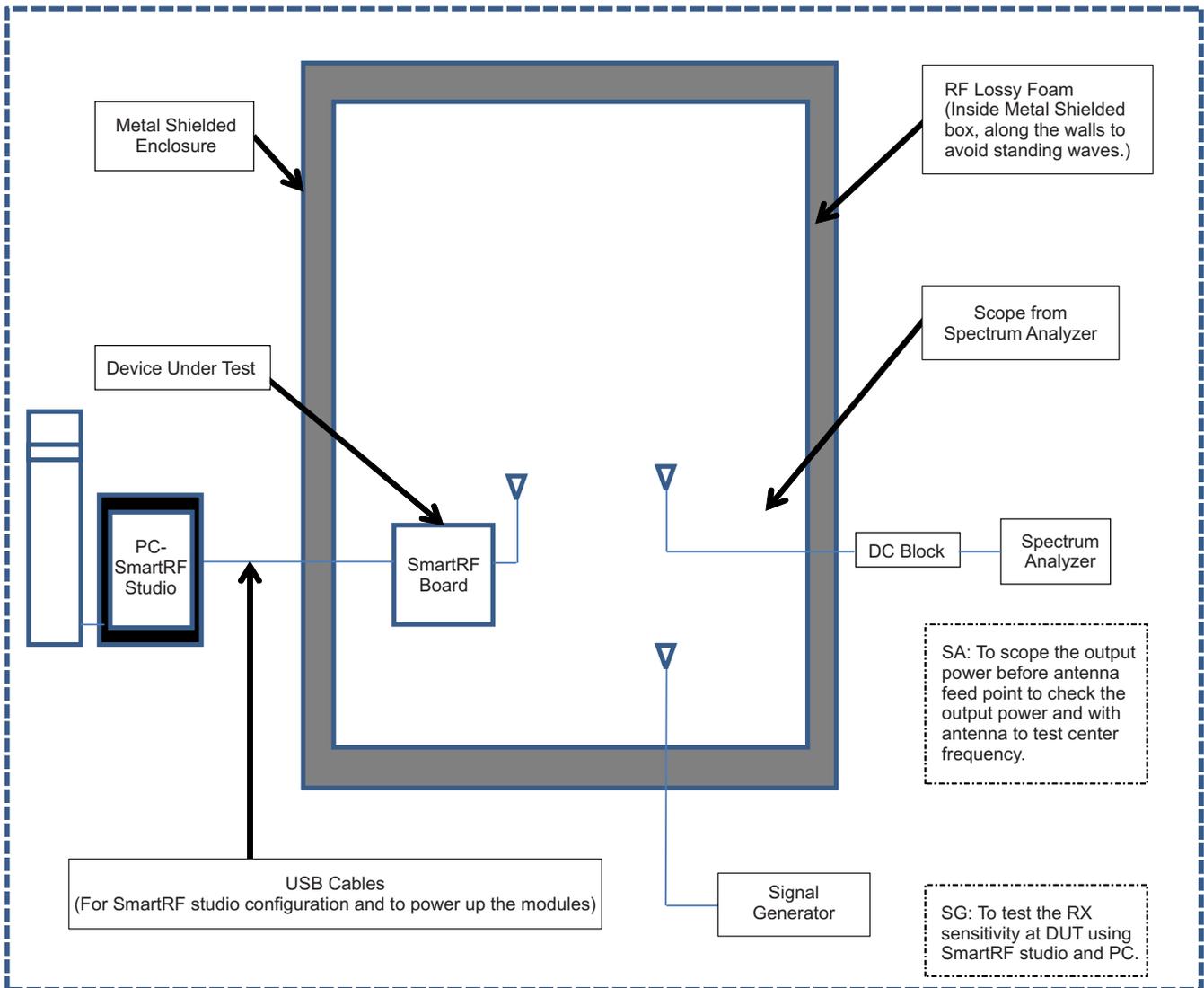


Figure 2. Suggestion 2: Setup Used in Production Line

4.2.1 Procedure for Setup-2

1. Output Power Test
 - (a) Using SmartRF studio, configure the DUT in Continuous modulated transmission (any fixed channel).
 - (b) Connect the sub 1-GHz/2.4-GHz antenna on a spectrum analyzer (SA). Configure SA for center frequency of the operating frequency band, for example, in the case of 2.4 GHz, that is, 2.45 GHz. Configure the start frequency as per operating frequency band, for example, in the case of the 2.4-GHz band, it is 2.4 GHz as a start frequency and 2.48 GHz as a stop frequency.
 - (c) Observe the peak on center frequency, that is, in 2.4-GHz band, at 2.45 GHz (Match the value of peak to reference TI EMK, noted beforehand).
2. Frequency Offset
 - (a) Using SmartRF studio, configure the DUT in Continuous modulated transmission (any fixed channel).
 - (b) Connect the sub 1-GHz/2.4-GHz antenna on SA. Configure SA for center frequency of the operating frequency band, for example, in the case of 2.4 GHz, that is, 2.45 GHz. Configure the start frequency as per the operating frequency band, for example, in the case of 2.4-GHz band, it is 2.4 GHz as start frequency and 2.48 GHz as a stop frequency.
 - (c) Observe the peak on center frequency, that is, in the 2.4-GHz band at 2.45 GHz (Match the value of peak to reference TI EMK, noted beforehand).
3. RX Sensitivity
 - (a) Using SmartRF studio, configure the DUT in Continuous Receiving (any fixed channel).
 - (b) Connect the sub 1-GHz/2.4-GHz antenna on Signal Generator (SG).
 - (c) Configure the SG for -50 dBm. Switch the RF output on the Signal Generator.
 - (d) Check the RX signal graph on SmartRF studio to -80 dBm.
4. Current Consumption
 - (a) Measure the current consumption by DUT in the previously completed tests and match it to the following (or the reference module tested thoroughly in your lab):
 - (i) Full power TX: In milliamps as per the configuration of with/without PA.
 - (ii) RX mode: In milliamps
 - (iii) Sleep/Idle Mode: In milliamps

4.3 Setup 3

The setup for production can have a provision for testing multiple modules at a time inside the shielded RF chamber (Figure 3). A customized board (INTERFACE BOARD) can be made for mounting, configuring and controlling all the boards at a time. This board can have an MCU on it to enable and disable the individual modules. The UART/SPI of MCU will be connected to UART/SPI of all the modules. The enabled module will only be responding to the testing process, one at a time. Putting all modules together inside the chamber will increase the throughput of production by eliminating the manual mounting and removal of single module again.

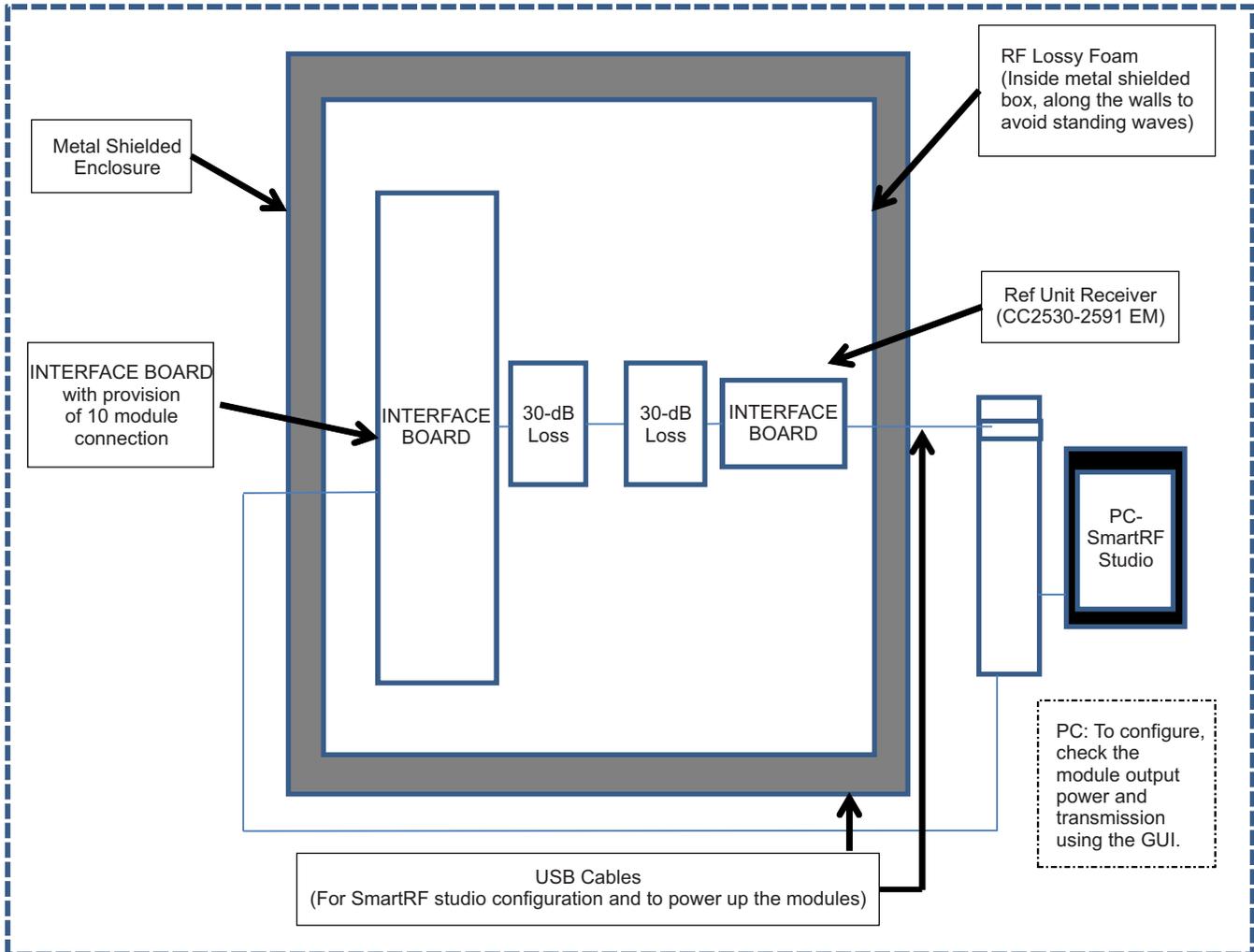


Figure 3. Suggestion 3: Setup to be Used in Production Line

Figure 4 illustrates the interface board block diagram.

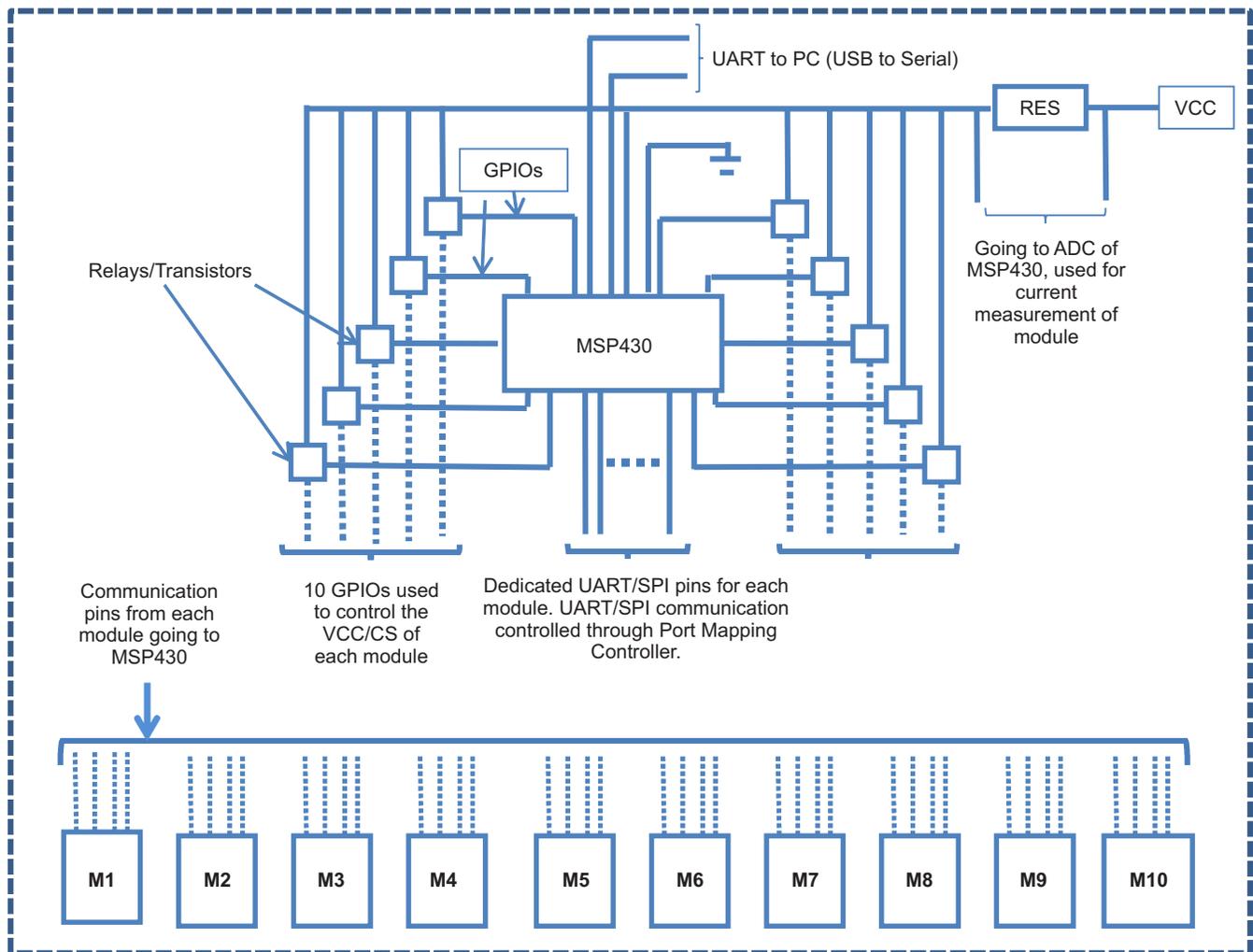


Figure 4. Interface Board Block Diagram

This interface board is connected to the PC and is controlled by a GUI. The GUI will configure the MSP430 for the start and stop of the test. The MSP430 then serially configures each module in transmission and receive modes to measure the values and then push back to the PC for a database creation. A simple serial command/packet interface can be developed to configure and read the desired registers from TI Radio. The command interface can have the following functions:

1. Configure the desired RF band channel.
2. Configure the module in Continuous TX/RX either in Modulated or Unmodulated mode.
3. Configure the Output TX power.
4. Read the Frequency Offset register to adjust and confirm the desired frequency signal. For example; using CC2530 – configure the FREQTUNE register, using CC1200 – configure the FREQOFF0/1 register to correct the offset. Refer to [Section 3.2](#) for details.
5. Read the RSSI register for reception quality analysis.

Develop and implement this command interface as needed, in the SOC or at the host of the LPRF module, keeping the interface as UART or SPI.

In the transmission mode of modules (DUT), the receiving is done through the GOLDEN module again configured and connected through the smaller interface board of the architecture seen in [Figure 3](#). In the reception test of modules (DUT), the transmission is done by GOLDEN module again configured and connected through the smaller interface board of the architecture seen in [Figure 3](#).

After completion of all test modes, the GUI will declare PASS/FAIL of each module.

There can be a tolerance limit for each measured parameter of the module; the range can be defined by performing these tests on a small lot of 50 modules who pass the performance figures through the lab equipment.

In [Appendix A](#), an example of the PC GUI is shown for the reference purposes only. In [Section 3.2](#), the interpretation of the RSSI, FREQEST, and FREQTUNE registers, of TI's LPRF radios, is provided to be used for testing and calibration purposes.

5 References

1. *SmartRF studio* by Texas Instruments (<http://www.ti.com/tool/smartftm-studio>).
2. *SmartRF Evaluation Board User Guide*, SmartRF05EB ([SWRU210A](#)).
3. *Interface Board Microcontroller, MSP430F6xxx User Guide* ([SLAU208](#)).
4. *CC253x/4x User Guide* ([SWRU191E](#)).
5. *CC112x User Guide* ([SWRU295](#)).
6. Agilent Spectrum Analyzer ([E-4404B](#)).
7. Agilent Signal Generator ([N-5181A](#)).
8. ETS -LINDGREN - Shielded Metal Enclosure Supplier (<http://www.ets-lindgren.com>).
9. NPI-VTECH Manufacturing Solutions (<http://www.vtechcms.com>).

Appendix A

Figure 5 shows the example GUI with an interface to 10 modules through the interface board using MSP430 for current measurement, configuration, and control of each module. The GUI allows the selection of the module position and respective RF parameters to be tested. The checkbox click allows the selection and deselection of the respective option.

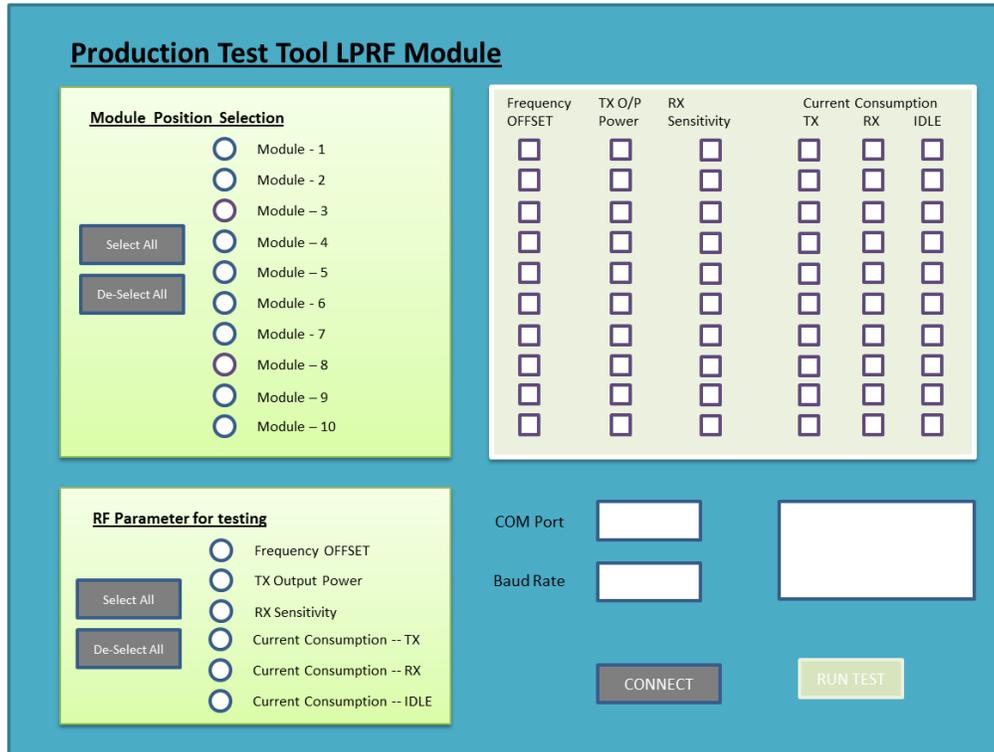


Figure 5. PC GUI Interface: Dash Board View

After selecting the respective module, the parameter test is enabled for the same and for the rest of the modules it gets disabled as shown in [Figure 6](#). The selection of the specific RF parameter can also be omitted for an enabled module, through the GUI. These options allow the capability to keep the entire test to be time optimized and precise.

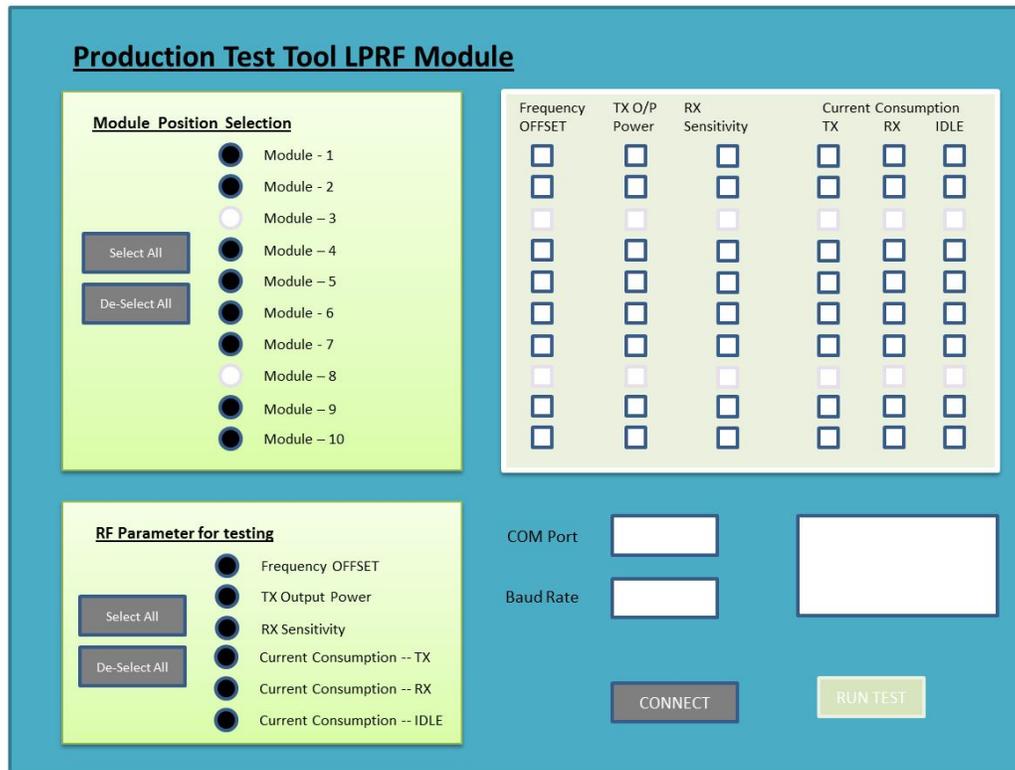


Figure 6. PC GUI Interface: Dash Board Selection View

[Figure 7](#) to [Figure 9](#) show how the PC GUI is configured and operated. [Figure 7](#) shows how the desired module and the RF parameter to be tested are selected. The respective serial COM port on which the interface board is connected must be selected and the configured baud rate needs to be entered in the PC GUI. After successful connection with the interface board only, the “RUN TEST”, button is enabled, ensuring the correct setup installation before the start of the module testing procedure.

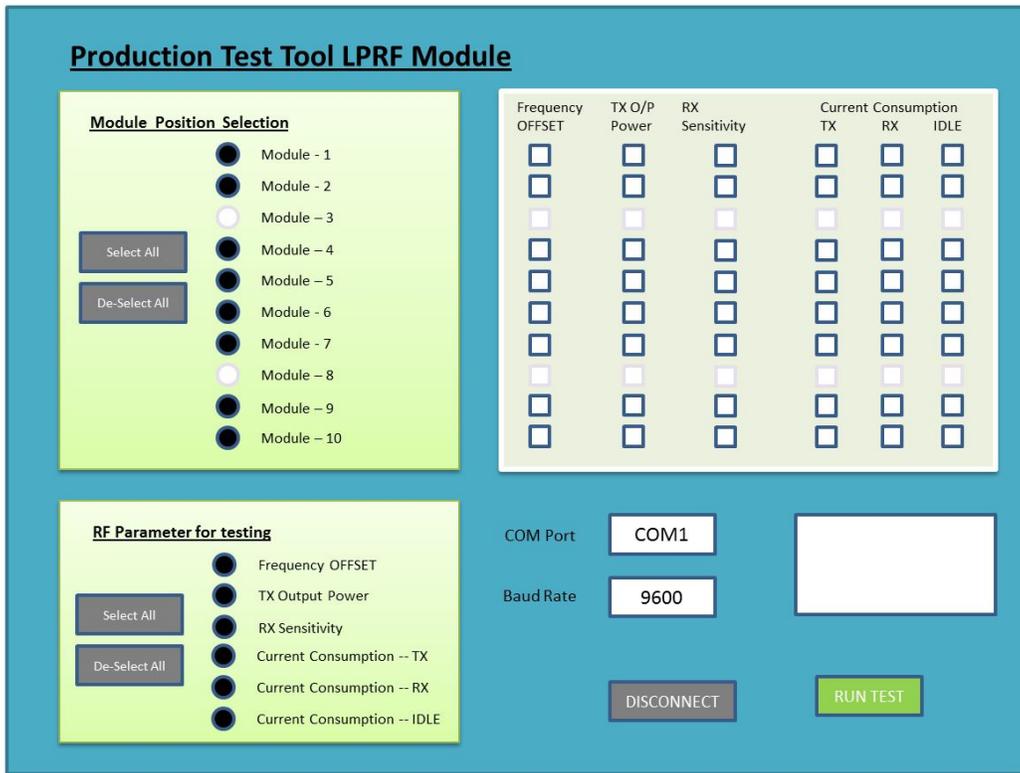


Figure 7. PC GUI Interface: COM Port and Baud Rate Configuration

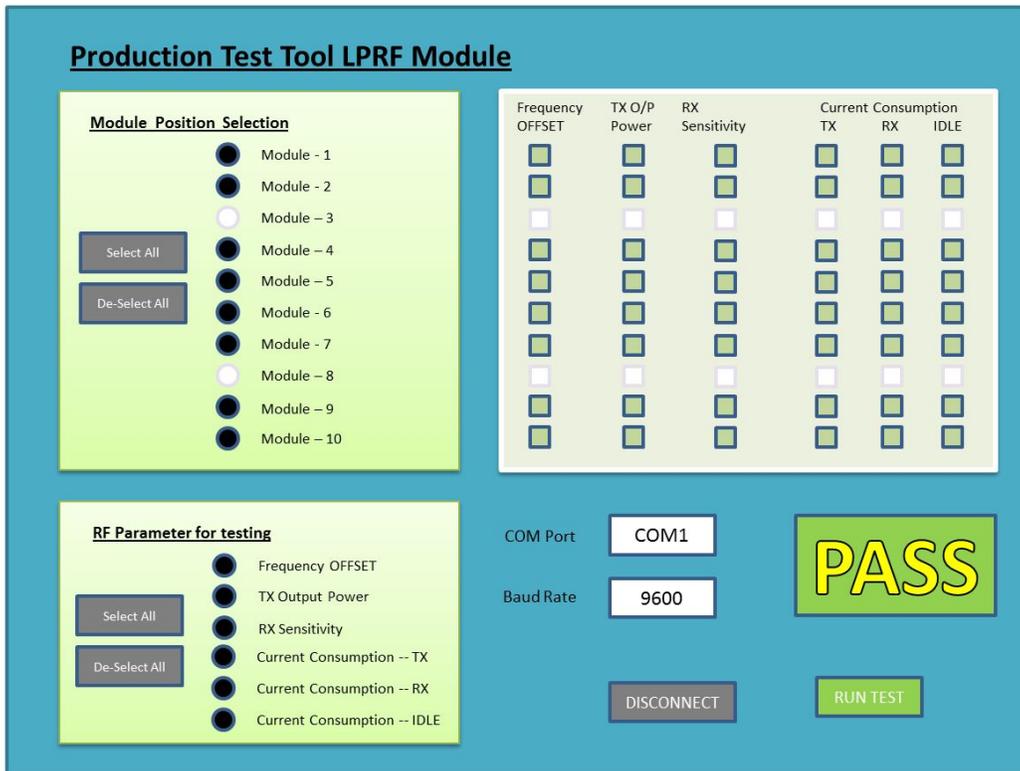


Figure 8. PC GUI Interface: Test Result View: Pass

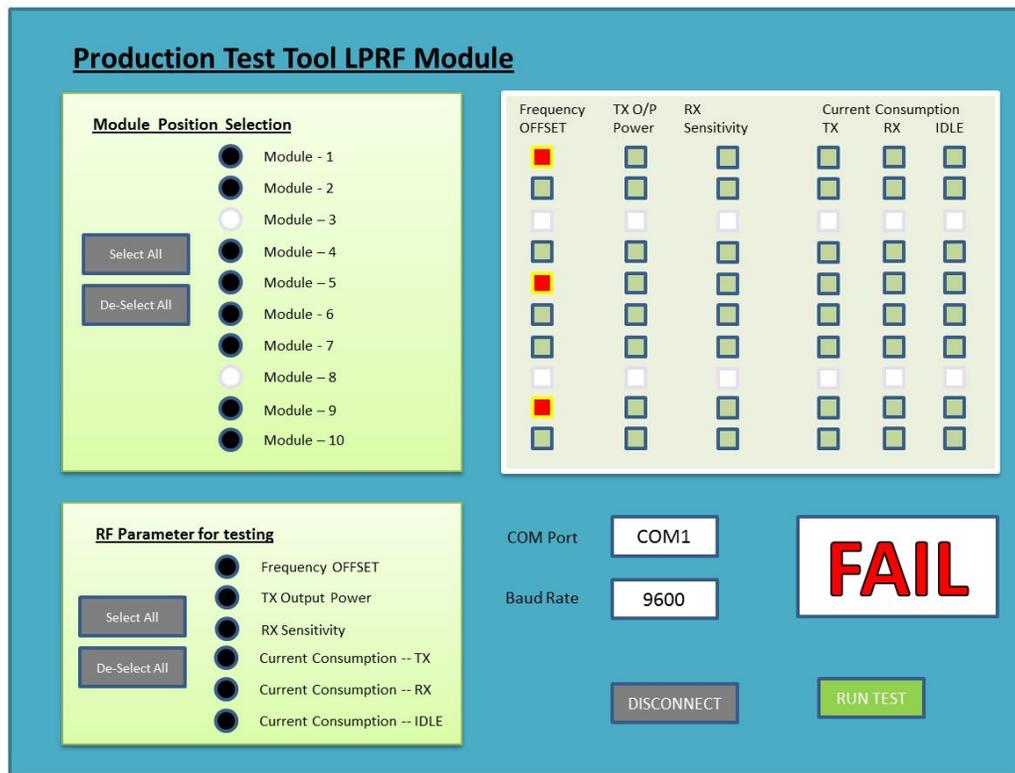


Figure 9. PC GUI Interface: Test Result View: Fail

A LOG report should also be created in the utility folder or the same can be displayed on the PC GUI for further analysis of the FAILED modules. Usually it is preferable to have a faster segregation of the modules as PASS and FAIL and then later a detailed failure analysis along with the rework. If desired select the option of stopping the test as soon as any failure of any module in the test occurs. Also, the report generation or display of results in the GUI can be made as per the preference and production line workforce capability. For example, in [Figure 9](#), the GUI indicates that modules 1, 5, and 9 have failed the Frequency OFFSET test. This means the OFFSET value is beyond the tolerable range. The issue could be due to the crystal, or the loading capacitors of the crystal, or the FREQTUNE register value.

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