In-Process Functional Test Cuts Cost of RF Products

Mike Dewey
GenRad, Westford, MA

A protocol-independent strategy isolates RF-component defects early in the manufacture of high-volume cable modems, set-top boxes, wireless phones, and PBXs.

A typical production line for today's complex PCB assemblies includes in-process and final test (**Fig. 1**). For RF products, however, many manufacturers forgo in-process testing because of limited access to nodes and the presence of small-value components that in-circuit test equipment cannot reliably measure. (For instance, in-circuit testers cannot reliably measure the 1-μH chokes and 1-pF capacitors commonly used in 900- and 1800-MHz products.)

But when manufacturers rely on final functional test alone, process-induced faults (like an erroneous substitution of a 10-μH choke for a 1-μH one) get discovered late in the manufacturing process. As a result, those manufacturers experience poor first-pass yields and incur debug and repair costs. To avoid these pitfalls, you can develop a test strategy that verifies the integrity of various RF functions early in the manufacturing process. We'll describe how to develop a test strategy for cellular phones, but you can apply many of the guidelines to other RF products.

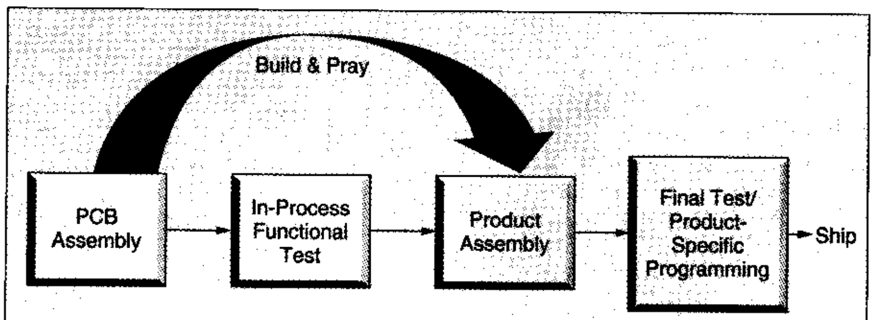

FIGURE 1. A typical manufacturing process begins with pick and place operations, continues through in-process test, and ends with product assembly and final test. Makers of RF products often rely on a "build& pray" approach that skips in-process functional test, to the detriment of final-test yields and overall manufacturing cost-effectiveness.

Defining an In-Process Test Strategy

To determine if using an in-process tester fits your product, you must predict end-of-line failure rates and the associated cost of debug and repair. Although the technology, protocol (GSM, CDMA, TDMA, or PCS1900, for example), and functionality of your product are unique, many manufacturing processes, fault spectra, and test requirements for in-process functional test may be generic.

A protocol-independent strategy provides several benefits:

- It employs general-purpose instruments and relies on software algorithms to process and analyze UUT data. You can create tests for a specific type of UUT as opposed to installing a new piece of test equipment for each new protocol.
- It is cost-effective. The in-process-test instruments do not have to support lengthy protocol-dependent operations like call setup.
- It is efficient. Often, you can move tests from final functional test to the in-process test stage.

To implement a protocol-independent test strategy, you'll need to perform basic RF measurements such as power, frequency, phase, and voltage. Because RF products share many functions and technologies, you can apply these basic tests to a variety of products. For example, all cellular products manufactured today operate at frequencies between 900 and 1800 MHz, and regardless of the specific protocol, these products all use digital modulation/demodulation technology. In addition, all RF products share common functional blocks that can potentially be tested with an in-process test strategy. **Table 1** provides a representative list of measurements you can use to test functional blocks within the product.

In formulating an in-process test strategy, you must define those tests that will help identify manufacturing-induced faults and will also confirm that the product is functional. Verifying functionality at in-process test will automatically ensure high first-pass yield at final test. As an added benefit, some amount of final functional test can potentially be incorporated into the earlier in-process tests, resulting in a shorter final-test time.

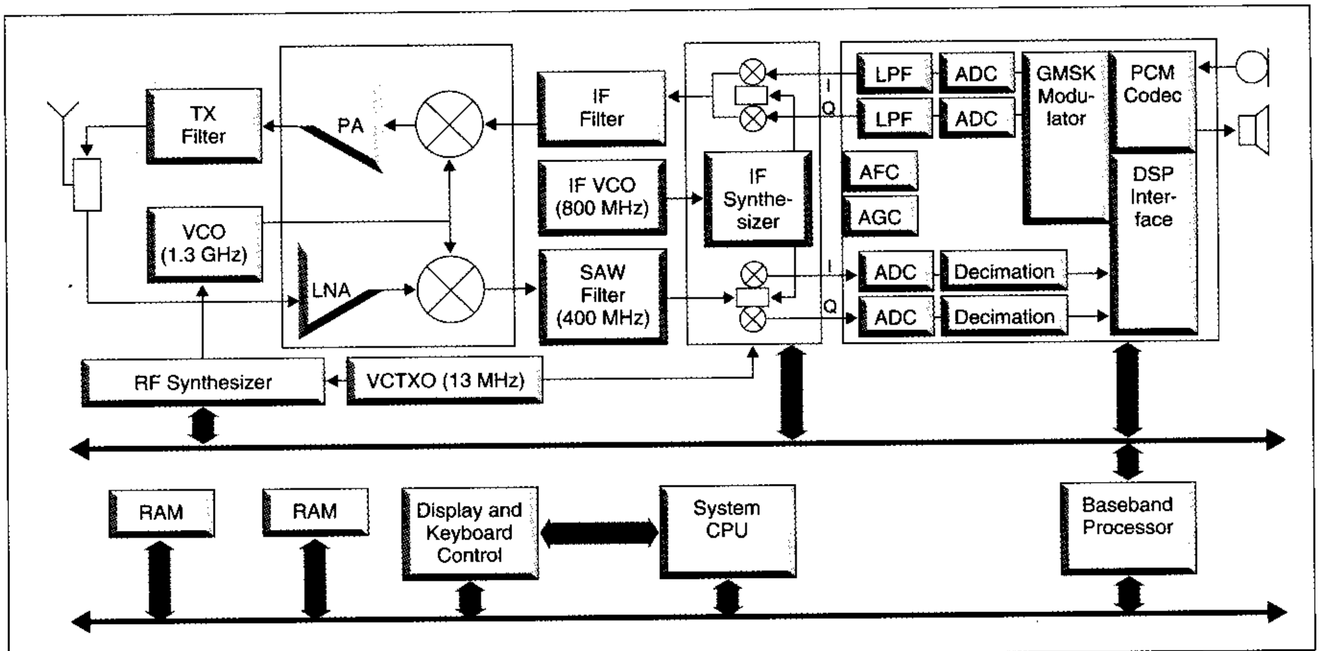

FIGURE 2. Although individual RF components resist in-circuit test, you can divide a GSM cell-phone handset into functional blocks amenable to in-process testing.

The functions detailed in **Table 1**, although independent of the product's specific protocol, require an assessment of UUT access and control. As a minimum, the UUT's antenna port must be available to support basic transmitter and receiver functions. For fixture design, you must take into account the use and placement of coaxial probes and requirements for integral shielding. You also must define techniques for isolating and accessing UUT nodes (including whether to use resistive isolation, integral directional couplers, capacitive probes, or inductively coupled probes). In addition, you need some type of low-level control—such as an RS-232C interface—to set up and monitor the UUT. Note that some of these techniques require incorporating test functions into the product's initial design.

An example of how you might deploy an in-process, functional test strategy is the manufacture of a GSM handset (**Fig. 2**). **Table 2** lists in-process functional tests that can verify the functionality of the handset's receiver and transmitter.

Note that by combining failure results from both groups of tests, you can indite or verify operation of the components in certain functional blocks. For example, correct frequency operation for receive and transmit tests would suggest that the product's synthesizer is functioning properly.

For this example, the test system (**Fig. 3**) consists of the following instruments:

• a VXIbus digitizer, which measures output power (to verify power-amplifier and synthesizer operation), verifies

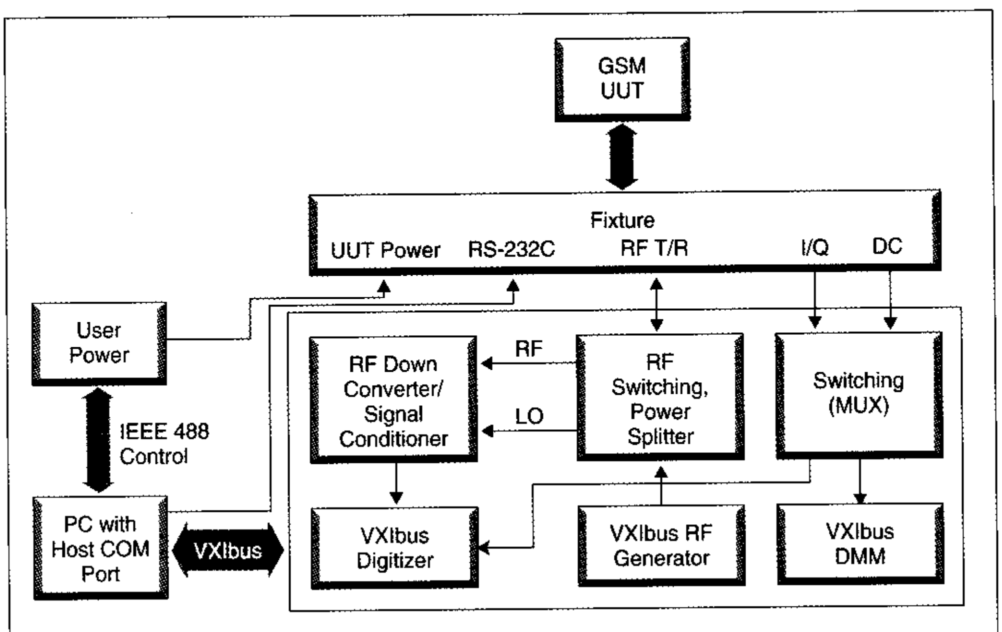

FIGURE 3. This in-process functional test system evaluates a GSM handset PCB. The UUT connects to a down converter/switching module, which in turn routes the signal to the VXIbus digitizer or generator. The system can be expanded to test multiple UUTs.

transmitter ramping functions, and analyzes the transmitter's phase error by employing a post acquisition algorithm.

- a custom RF interface module comprising a down converter, power splitter, and RF switching. The down converter provides an IF compatible with the VXIbus digitizer's bandwidth and sampling capabilities.
- a VXIbus RF generator; the RF generator provides the local oscillator (LO) for the down converter and also provides a CW and FM signal for evaluating the handset receiver's receive signal strength indicator (RSSI) as well as its automatic-gain-control AGC vs. RF-level and IF bandwidth/filter performance.

To perform the in-process tests, you must have some simple control that lets your tester program the handset's synthesizer and initiate the transmitter's operation. You also need the requisite connection to the UUT's antenna port and, in this GSM example, access to the I/Q and RSSI/AGC voltage nodes. A tester also can perform calibration or flash programming at this test stage.

As noted earlier, you may be able to move some end-of-line tests to in-process test. For example, ETSI-defined GSM measurements such as

Table 1. RF Functional Blocks and Test Parameters

Functional Block	Measurement
Synthesizer	Frequency
	Frequency vs. VCXO Tuning Voltage
Power Amplifier/Transmitter	RF Power
	Power Ramp Up/Down
Up/Down Converter	Frequency & Level (Conversion Loss)
RF Amplifier/Receiver	AGC Level
	RSSI Level vs. Signal Level
IF Filters	Level vs. Frequency
Modulator/Demodulator	Transmitter Phase Error
	I/Q Phase Error
Digital Control/CPU	Serial Interface I/O
UUT Power Consumption	DC Power Measurement

The Case for In-Process RF Test

Although a few manufacturers reach the 6σ quality level at final test, many manufacturers routinely exhibit failure rates of 4%, with failure rates of more than 10% not uncommon for some second-tier manufacturers.

For manufacturers producing even moderate volumes (for example, 1 million products per year), a failure rate of 4% results in significant rework costs—an aggregate labor cost can reach $250 per hour when you include ammortized costs of repair station equipment, scrappage, and time costs for the skilled RF engineers required to troubleshoot a plastic-encased product that's not designed to be disassembled.

To understand the economics of deploying an in-process, functional test strategy, first consider the following sample statistics for manufacturing GSM handsets with final functional test only:

- 1 million units/year production volume,
- 2 min. final test,
- 4% failure rate at final test,
- 40,000 defective units,
- $250/hr., 30-min./unit repair costs, and
- $5 million annual repair cost.

Now consider the economics of using an in-process test strategy:

- 1 million units/year production volume,
- 1 min. in-process test,
- 4% failure rate at in-process test,
- $90/hr., 30-min./unit post-in-process-test repair costs,
- 1.5 min. final test (assumes some previous final tests occur during in-process test),
- <1.5% failure rate at final test,
- $250/hour, 30-min./unit post-final-test repair costs,
- $3.675 million annual repair costs, and
- 2.5 min. per unit total test time.

The in-process test strategy yields $1.325 million in annual savings, at the cost of a 0.5-min./device increase in test time and an investment of about $300,000 in an in-process test station with handlers. If the increased test time slows the production-line beat rate to an unacceptable level, you could add a second in-process test station and still save $725,000 the first year.

This analysis does not account for the cost of the floor space required for the in-circuit test stations, but those costs are offset by reducing the scrappage that results when disassembly of a handset's plastic case irreparably damages internal PCBs. **Figure A** illustrates annual savings vs. percent failure at in-process test by instituting an in-process functional test strategy.—*Bob Stasonis, GenRad*

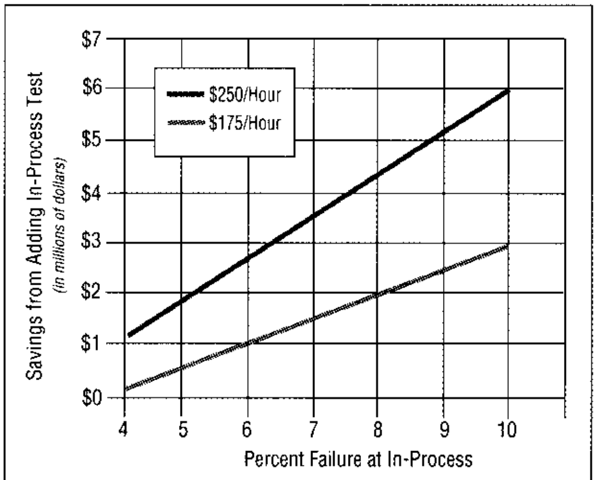

FIGURE A. Reinstating in-process test in the manufacture of RF products can cut manufacturing costs, for a range of in-process-test failure-detection rates.

power ramping, power level, power-level-setting accuracy, transmitter phase error, and frequency error can occur in process, eliminating several end-of-line tests.

Although this article has concentrated on cellular phone technology, you can use similar measurement techniques for other types of RF products. The key to a successful deployment of this strategy is to have a product with some test access and control along with a compelling economic case. Adoption of this test strategy will help solve the manufacturing costs and quality issues not only today, but also in the future, because the protocol-independent strategy provides the means to redeploy the test system and ramp up production for next-generation products quickly and easily. *T&MW*

Mike Dewey *is product line manager for GenRad's VXIbus-based Geneva functional test system.*

Table 2. In-Process Tests and Indicated Faults

Functional Block	Test	Measurement	Faults Indicated
Receiver	Apply an RF signal with unit configured for non-burst mode	Verify AGC/RSSI DC level vs. RF input level	Synthesizers, VCOs, demodulators, or filters
		Verify IF bandwidth by offsetting the carrier	
		Verify I/Q outputs by shifting carrier 10 kHz	
Transmitter	Program unit to various output power levels	Measure output power level and frequency via test system's down converter and digitizer	Matching networks, RF switches, synthesizers, or VCOs.
	Apply phase-analysis algorithm to the acquired array	Analyze transmitter phase error	Modulator, power-amplifier linearity, and synthesizers
	Ramp up/ramp down burst	Analyze transmitter's output burst level and shape, via digitized IF	Ramp shaping circuit

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