Application-specific instruments for high volume manufacturing speed RF and DC measurements

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By combining today's intelligent instruments, manufacturers can significantly increase testing throughput for RFIC power amplifiers and mobile phone handsets.

A key competitive advantage for many manufacturers of power amplifier RFICs and mobile phone handsets is cost-effective high production throughput. With continual cuts in capital expenditures, companies are looking for easily supported solutions to increase capacity. With test costs approaching five to ten percent of the unit cost, minimizing test time can have immediate bottom-line impact. For manufacturers to be competitive, mobile phone PC boards must be tested and calibrated in less than a minute. RFIC power amplifier manufacturers must test their devices in just a few seconds.

The keys to fast and economical testing are to choose instruments best suited to the task and to eliminate the bottlenecks that increase testing time. This article will look at both of these areas and explain how they can achieve important gains in test throughput.

Choosing the Appropriate Instruments

Combining a few key test instruments will allow testing RFIC power amplifiers and mobile phone PC boards; in many cases, this combination of instruments will result in higher throughput and less overall rack space. Using a collection of general-purpose laboratory instruments is appropriate during product development, but not for production test, which demands application-specific instruments that optimize the needed measurements, and nothing else. For example, typical board-level mobile phone testing includes a power meter, spectrum analyzer, signal generator, DC source, DMM, and a controlling PC. By using a specialized RF power analyzer, both the power meter and the spectrum analyzer can be replaced. The RF power analyzer can maintain sufficient accuracy for the testing application while also offering the frequency selectivity of the spectrum analyzer. An RF power analyzer offers a 20% to 40% cost savings over the two instruments, a 4× speed advantage over conventional spectrum analyzers, and a space advantage, consuming only 2U (3.5 inches) of rack space. Furthermore, wireless device power sources combine specialized, fast-transient voltage sourcing capability and current measurement to eliminate the cost of a separate DMM and extra circuit components to provide both DC and pulsed source-measurement performance in a wireless device test system.

Combining these production-optimized instruments—an RF power analyzer, a fast-transient power supply, an RF source, a source-measure unit, and an audio analyzing DMM—makes it easy and economical to configure a high speed wireless phone transmitter/receiver calibration station at about half the equipment cost of current test solutions in no more than 6U of rack space. This system's high throughput can also cut test time and increase production capacity.

The same optimizations can be realized in the functional packaged part testing of RFIC power amplifiers. Testing of these devices closely resembles the testing methods of PC board level mobile phones. In a production environment, a device handler places each RFIC power amplifier in a test socket and triggers the test system to initiate testing. The test system first performs continuity checks on each IC pin, and then

Figure 1: The Keithley Model 2800 RF Power Analyzer is intended for production testing of cell phones and RFIC power amplifiers.

executes a combination of DC tests and RF measurements, which are performed in the most efficient order. Once the measurements are complete, the test system makes a pass/fail decision on the device under test (DUT), and then triggers the handler to put the DUT just tested into the appropriate bin and place the next device in the test fixture socket. More complex test systems will use handlers with two test sockets, increasing throughput by allowing one device to be tested while a second one is moved into or out of the second socket. Efficient interfacing of the instrumentation with the handler is essential for optimizing device throughput.

We'll look at three of the major components of such a test setup: the RF power analyzer, the fast transient power supply, and the source-measure unit.

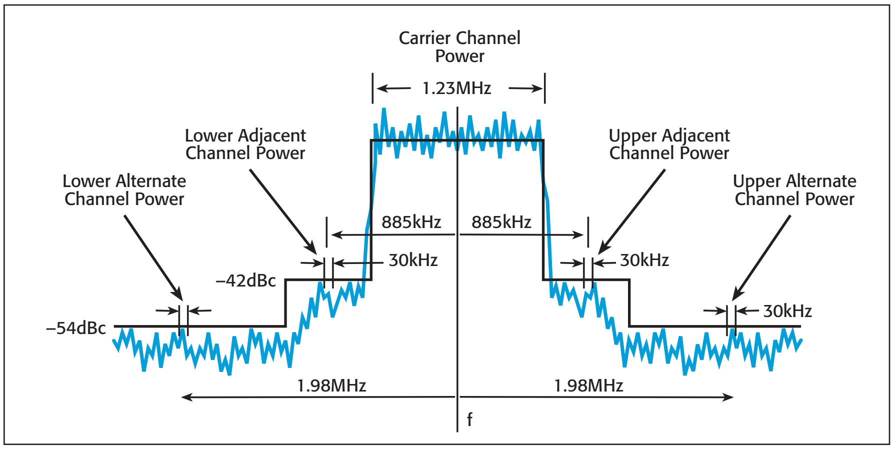

Figure 2: The Model 2800 can perform this 1.23MHz bandwidth cdmaOne primary power measurement and transfer the measurement to a computer in 6ms.

RF Power Measurement for Fast Calibration and Functional Test

The measurement of RF power is key to the testing of an RFIC power amplifier. These measurements need to be performed accurately and quickly. An RF power analyzer can fill both of these needs.

An RF power analyzer (***Figure 1***) is a specialized instrument for production testing of RFIC power amplifiers and mobile phone handsets. Rather than having a frequency bandwidth that will not be used in the production test environment, it optimally measures RF power and frequency over defined bandwidths and frequency ranges. Instead of a sweeping oscillator, it uses multiple oscillators for the multiple narrow bands it measures. This increases measurement speed, because frequency changes are very quick. It has no built-in graphical display but reports its results directly to a computer. Processing time required to update a graphic display is not needed, further reducing measurement time. The RF power analyzer is, first and last, a production test instrument. It's a better choice than a spectrum analyzer for production testing of mobile phone handsets and power amplifier RFICs for several reasons:

- *It's much faster*—An RF power analyzer is from four to ten times faster for mobile phone production tests than a spectrum analyzer. For example, it can make a 1.23MHz bandwidth cdmaOne primary power measurement (***Figure 2***) and transfer the measurement to a computer in 6ms. It can make a 3.84MHz bandwidth primary channel measurement in 10ms, and can make power measurements on consecutive 577 microsecond GSM pulses occurring every 4.6ms. The power analyzer, in an optimized GSM mode, can measure eight consecutive power bursts, representing all eight time slots in the 4.6ms GSM frame. Thus, testing time of a GSM power amplifier or calibrating a GSM mobile phone transmitter circuit can be reduced by at least a factor of four to six. In addition, an RF power analyzer can make multiple simultaneous measurements; it can make a total of five measurements—cdma2000 1X primary power, upper adjacent power, lower adjacent power, upper alternate power, and lower alternate power—in only 26ms (including PC command time and time for data transfer to the PC). A GSM primary power measurement and two spurious power measurements take only 14ms.
- *It's easy to set up*—Because it is intended for certain specific tests, an RF power analyzer has the parameters for those tests pre-programmed. It can be set up from the front panel using a menu, or by computer via an IEEE-488 link. It can take just five GPIB commands to measure and transfer five readings—carrier channel power, upper adjacent channel power, lower adjacent channel power, upper alternate channel power, and lower alternate channel power—to the external PC controller. A spectrum analyzer may take from two to eight times as many commands to do the same job.
- *It's much less expensive*—A representative top-of-the-line spectrum analyzer with the features necessary for mobile phone testing costs more than $20,000 while a communications analyzer can run from $40,000 to $80,000. An RF power analyzer is a fraction of that, at about $16,000.
- *It saves space*—An RF power analyzer often takes up just 3½ inches of rack space. Top-of-the line spectrum analyzers run from 7 to 9 inches high; two RF power analyzers could be put in the same rack space.

DC Sourcing and Measuring for Battery Simulation and Load Current Monitoring

Another important element in RFIC power amplifier and mobile phone handset testing is the ability to properly supply and monitor a stable DC voltage and measure load current. Since the tested device will be used with a battery source, the ability to closely mimic an actual battery and monitor the current that will be drawn from the battery is essential. This requires a power supply (***Figure 3***) with both variable output voltage and variable output impedance, which closely duplicates the voltage characteristics of a battery during energy drain. The power supply should also have an ultra-wide bandwidth output stage that responds quickly to sudden changes in load caused by "burst" communication protocols like TDMA and GSM with minimal transient voltage droop and recovery time. If power supply output voltage (V_{cc}) drops when the device changes from a standby state to a full-power transmit state and draws large current pulses, it may

Figure 3: The Keithley Model 2306-VS Fast Transient Power Supply features source-measure triggering, variable output impedance, and programmable voltage stepping.

cause a mobile phone PC board to go into low-voltage shutdown, which creates false rejects. The power supply's ability to respond quickly to transient load changes and maintain a stable output voltage prevents false failures. Extra test time is avoided, and production line yield is improved. Furthermore, the ability to respond quickly to transitions from the standby state to the RF transmission state and minimally disrupt the supply voltage enables the RF circuitry to draw the appropriate amount of current, especially if the operation is a TDMA burst mode. Ensuring that the DUT can draw the needed current ensures that the DUT's RF output can be properly calibrated or that the RF output can attain the maximum power levels defined by its specifications. Being able to simulate a battery's internal resistance allows testing of the DUT under end-of-charge conditions where battery voltage is low and internal resistance is at its maximum value. The DUT's performance under worst-case conditions (where it draws maximum load current at the low battery threshold level) can be verified under the most realistic conditions.

In addition to accurate battery simulation, it is very helpful to have a read-back power supply that can accurately measure load currents—both DC currents and pulsed currents. This eliminates the need for a separate instrument to measure dynamic power consumption for comparison to test specs. Also a wide current measurement range is essential. Mobile phones and RFIC power amplifiers have sleep mode or idle mode load currents in the microamp range. Standby current levels are in the 50mA to 200mA range, while full power RF transmissions can require peak pulses greater than 2A. For RFICs, an accurate computation of efficiency can be derived from the DC power parameters provided by the fast transient supply and the RF instrumentation.

During a typical power amplifier functional test, it is common for the test suite to use multiple DC voltage changes to replicate operation of the PA under extreme DC voltages. It is imperative that the DC supply makes these multiple setpoint changes quickly without large overshoots.

Specifically for RFIC power amplifier functional test, the device is tested at maximum and minimum voltage operating levels. The device may also be stressed by stepping operating voltage levels from minimum levels to slightly higher than the maximum recommended operating voltage. DUT performance during this test sequence can assess the quality of the die attachments and indicate die bond voids. The challenge is to do this quickly. Conventional power supplies tend to be slow when making voltage level changes, which can take up a significant amount of RFIC power amplifier test time. Fast transient response supplies can make fast voltage transitions. ***Figure 4*** shows a 160-microsecond voltage transition. In addition, fast transient supplies are available that store test sequences consisting of a number of voltage levels such that the supply can output a sequence of voltage levels under its own control. Thus, time-consuming IEEE-488 interface bus traffic is minimized, since just one command is needed to initiate the sequence of voltage levels rather than a separate command for each voltage level. External triggering on these supplies permits fast hardware interfacing with other instruments. This further reduces test time by eliminating IEEE-488 control commands. ***Figure 5*** shows how a sequence of four voltage steps can be made in 1.5ms.

DC Sourcing and Measuring for Accuracy and Control

A source-measure unit (SMU) finds many uses in RFIC testing power amplifier. It can source voltage while making precise current measurements, source (or sink) current while making extremely precise voltage measurement, and be preprogrammed for high speed.

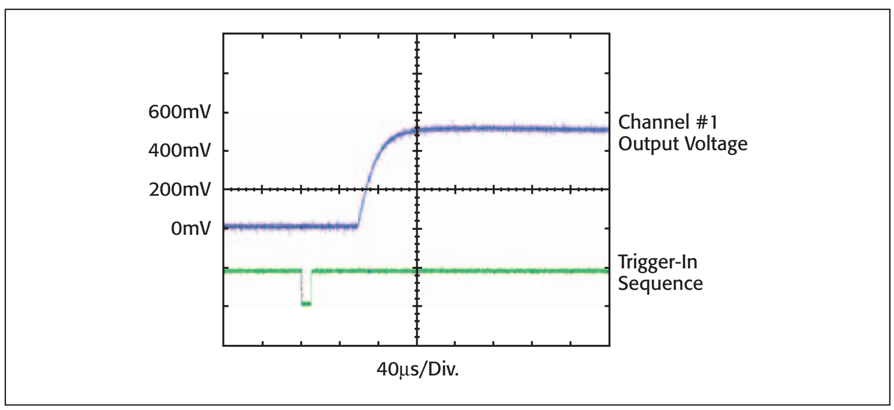

Figure 4: A fast transient power supply can make a 500mV voltage transition in just 160 microseconds.

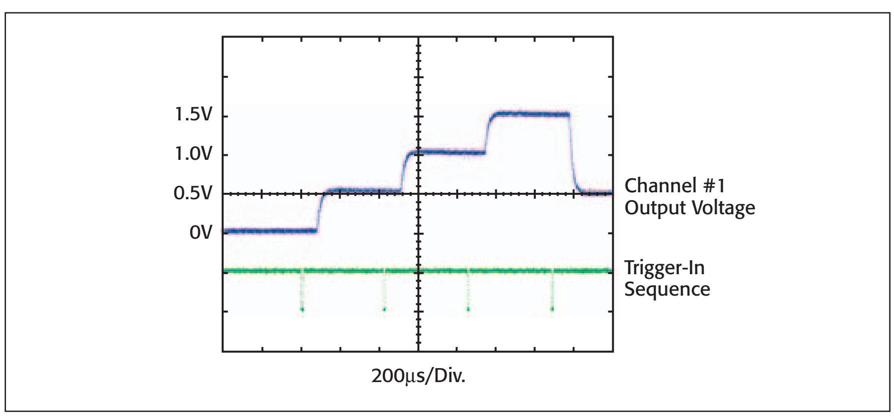

Figure 5: Preprogramming a fast transient power supply allows it to make a sequence of four voltage steps in 1.5ms.

Source-measure units can provide precise voltages for control lines of RFIC power amplifiers. In addition, they can measure device quiescent currents with sensitivity levels down to 50pA. Using the controlled current source mode, pin continuity can be quickly verified. SMUs also interface directly with device handlers. Thus, SMUs can control test sequencing independent of a controller to enhance device throughput. Many RFIC test setups require several SMUs for the different DC bias inputs to the chip.

Avoiding the GPIB bottleneck

Probably the biggest single contributor to reduced test time results from preprogramming instrumentation to automatically execute test sequences independently of the PC. For many applications, GPIB-controlled measurements are no longer fast enough. Today's RFIC tests are so complex, and the need for speed is so great, that GPIB's communications overhead is no longer tolerable. And if a PC runs a test setup, the test is slowed still more by Windows' extensive—and unpredictable—latencies in responding to communications.

Instruments are needed that will run themselves. Many of today's instruments can be preprogrammed with entire sets of test sequences that can run without PC intervention. The RF power analyzer, the fast transient power supply, and the SMU can be set up in advance with test sequences, then started with a single command. As each instrument makes a measurement, it uses its hardware triggers to communicate with the other instruments and initiate subsequent measurements until all tests are complete.

Efficient use of IEEE-488 bus communication is also critical to reducing test time and improving throughput. Test data should be transmitted over the bus during the time that new devices are being switched into the test fixture or when switching from one device to another on a dual-device fixture. This minimizes instrument idle time and ensures maximum device utilization.

Conclusion

RFIC and mobile phone manufacturers must optimize test performance and minimize costs. Application-specific instruments that can run entire test sequences without outside intervention can greatly speed the test process and save both time and money—and every second saved has a major bottom line impact when producing tens of millions of devices for the high volume wireless device market. KEITHLEY

About the Authors

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