Optimizing Throughput in Transmit/Receive Module Test

Application Note

Overview

Radar, satellite and electronic warfare (EW) systems utilize a wide variety of microwave modules. Across these applications, a common set of issues tends to occur during testing in the engineering and production environments. This application brief illustrates those issues by focusing on transmit/receive (T/R) modules used in radar systems.

T/R modules are produced in large quantities for use in phased-array radar systems such as the one shown in Figure 1. The T/R hardware is used behind each antenna element in a phased array, potentially requiring hundreds or thousands of modules in a single radar system.

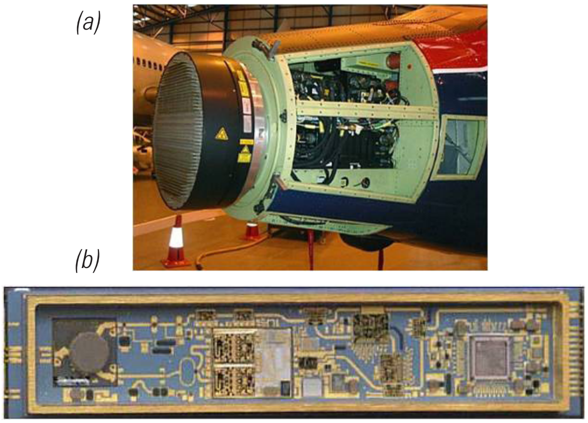

Figure 1. Today's phased-array radars (a) may include thousands of T/R modules (b) that often require extensive testing.

T/R modules are either part of the antenna or are the device closest to the antenna. As a result, they have a major effect on the RF performance of the radar. During transmit operations the output RF pulse is amplified by this module, thereby defining the maximum radiated power of the radar. During receive operations the low-noise amplifier (LNA) within the module input defines the system noise figure and consequently the minimum detectable signal. Within each path, programmable phase shifters and attenuators control the antenna beam-steering and determine the angular accuracy of the radar.

Problem

When a phased-array radar includes thousands of T/R modules, test throughput becomes a critical requirement. T/R modules typically need extensive testing to ensure that they all match across the phased array in which they are used.

To complicate matters, many such modules are smart devices that operate in a variety of modes and require multiple commands from the ATE platform for each test. In addition, each module is tested at multiple steps in the assembly process and traceability is required from step to step.

The overall cost of test is directly related to three major factors: the labor burden, the equipment cost and the total test time accumulated across all steps in the process. Historically, test throughput has been improved by eliminating procedures that are most affected by speed limitations in the test instruments. Equipment cost is primarily a function of the microwave measurements required, and has a much smaller effect on total cost than does test time.

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Solution

Properly evaluating the performance of every T/R module requires a broad array of measurements (Figure 2). Because the T/R module is the front end to the receiver, it requires typical measurements such as noise figure, spectral response, and gain and input match.

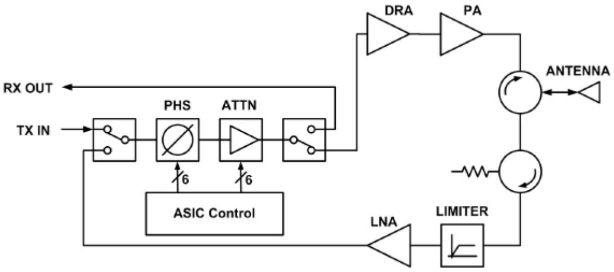

Figure 2. T/R modules are the main interface between a radar antenna and its receiver. The active components, phase shifters and variable attenuators require testing in multiple test states.

The most time-consuming input measurement is usually characterization of the attenuator and phase-shifter responses. These are typically interactive because the attenuator affects the phase shifter and vice versa. As a result, each can have between 32 and 256 possible states, resulting in a very large number of tests if all permutations are measured. Because these states are frequency-dependent, they are typically measured at multiple frequencies. It's important to note that the measurements cannot be made by simply sweeping the device under test (DUT) response with a vector network analyzer (VNA) because the measurement at each data point requires a change in DUT state.

Similar measurements are performed to characterize transmitter performance. For example, the same gain and output matching parameters are typically measured, as are attenuation and phase programming (with the same issues as for the receiver). Noise figure and spectral response are replaced by N dB compression or maximum output power versus frequency. Because the transmitter is operated in pulsed mode, output pulse parameters are typically measured: examples include the phase and amplitude ripple across the pulse; pulse width; and rise and fall times.

The final set of measurements includes general module parameters such as timing, current draw and status. Timing delays may be adjusted to optimally align module timing when switching between transmit and receive modes. Once all of the characteristic measurements have been completed, it is common practice to download calibration factors into EEPROM in the module's ASIC controller. Additional measurements are then performed to confirm correct, calibrated operation.

Measurement overview

A large number of measurements may be required to characterize each channel of a T/R module. The actual number may be 25 or more with numerous variants, depending on the manufacturer and application (Table 1).

Table 1. Typical measurements on T/R modules

Module section	Key measurements

Receiver	• Gain and VSWR vs. frequency
	• Noise figure vs. frequency
	• Spectrum: harmonics, spurious and intermodulation
	• Attenuation and phase shift vs. frequency
	  • Programmable (five to eight bits for each)
	  • 1,000 to 65,000 states per frequency

Transmitter	• Gain and VSWR vs. frequency • Attenuation and phase shift vs. frequency • Compression (maximum transmitter power) vs. frequency • Pulse profile: phase and amplitude; pulse width; rise and fall times
Other	• Timing delays (programmable) • Current: peak and average • Module status

At some point in the development process, the engineering team may perform all of these measurements. In contrast, a subset is usually performed on the production line, and the test limits are based on statistical ranges created by engineering. The actual number of measurements made in production varies by manufacturer and also depends on factors such as T/R module characteristics and contract requirements. If the test time drops below a certain threshold, manufacturing groups often forgo faster throughput and instead choose to use a greater number of tests because the extra data can significantly reduce the amount of testing needed during final integration.

For comparison purposes, assume a T/R module with a six-bit phase shifter and a six-bit attenuator. The trend in T/R modules is for higher density, with more than one channel per package. The number of channels can range from as few as one or two to as many as 16. As an example, assume the T/R module has four transmit channels and four receive channels. Complete characterization of such a module—covering all combinations of phase and attenuation settings—requires more than 100,000 measurements, as shown in Table 2.

Table 2. The total number of measurements required to characterize a T/R module (highlighted measurements represent longest test times)

		Ideal requirement		
Measurement	**Chan**	**Pts**	**Freqs**	**Total**
RCVR gain and VSWR	4	2	201	1608
RCVR noise figure	**4**	**1**	**11**	**44**
RCVR phase and attenuation	**4**	**4096**	**3**	**49152**
RCVR spectrum	4	2048	1	8192
XMTR gain and VSWR	4	2	201	1608
XMTR phase and attenuation	**4**	**4096**	**3**	**49152**
XMTR compression	**4**	**1**	**201**	**804**
XMTR pulse profile	4	20	1	80
Timing	4	24	1	96
Supply current	4	3	1	12
Module status	1	1	1	1
Total measurements				**110,749**

Additionally, all of the measurements are performed at more than one gain/phase state to ensure linear behavior. One comment: The above example used six-bit attenuators and phase shifters; however, current modules use 8-bit components, which would increase the number of test states.

Note that it is unsafe to measure a T/R module's rise, fall and pulse-width time unless the system-generated stimulus pulse is wider than the ASIC gated transmit time (i.e., the module cuts the pulse from a continuous wave (CW) signal). The signal generator in the test system usually has a slower rise time than the module being measured.

Throughput tradeoffs with a legacy system

With a typical legacy test platform, it would take more than 10 hours to perform such an extensive set of measurements. Three tests are the main contributors to the long time: phase and attenuation (due to the very large number of test states); compression; and noise figure.

Clearly, 10-hour test times are not feasible in a production setting. In reality, a 10-hour test time is an obstacle in engineering too, especially if there is a need to characterize the T/R module over a range of temperatures. The long test time makes it unlikely that a complete set of measurements would be made on a regular basis.

The simplest way to achieve a shorter test time is to reduce the number of measurements, especially for phase and attenuation. For example, a significant amount of time can be saved with two changes: all phase states are measured at a single attenuation setting, and all attenuations are measured for a single phase state (but not all combinations of both). Testing phase and attenuation in this manner verifies operation of the two programmable devices, but does not completely characterize operation of the overall T/R module, nor does it map interactions between the two.

Test times are long for NF and compression because they require a large number of frequencies. Similar to the reductions achieved with phase and attenuation, reducing the number of frequencies can accelerate the testing process.

With these changes, total test time for a four-channel device can be reduced to a more manageable 10 to 20 minutes. This will be much more cost-effective on the production line.

Table 3. T/R test solutions based on the Agilent X-Series will provide tremendous improvements in throughput. The reduction of measurements to reduce test time on the legacy T/R system is no longer required with Agilent's X-Series T/R systems.

		Legacy T/R Test System						Agilent X-Series T/R Test System		
		Ideal requirement			Reduced for production			Ideal requirement		
Measurement	**Chan**	**Pts**	**Freqs**	**Total**	**Pts**	**Freqs**	**Total**	**Pts**	**Freqs**	**Total**
RCVR gain and VSWR	4	2	201	1608	2	201	1608	2	201	1608
RCVR noise figure	**4**	**1**	**11**	**44**	**1**	**3**	**12**	**1**	**11**	**44**
RCVR phase and attenuation	**4**	**4096**	**3**	**49152**	**128**	**3**	**1536**	**4096**	**3**	**49152**
RCVR spectrum	4	2048	1	8192	2048	1	8192	2048	1	8192
XMTR gain and VSWR	4	2	201	1608	2	201	1608	2	201	1608
XMTR phase and attenuation	**4**	**4096**	**3**	**49152**	**128**	**3**	**1536**	**4096**	**3**	**49152**
XMTR compression	**4**	**1**	**201**	**804**	**1**	**3**	**12**	**1**	**201**	**804**
XMTR pulse profile	4	20	1	80	20	1	80	20	1	80
Timing	4	24	1	96	24	1	96	24	1	96
Supply current	4	3	1	12	3	1	12	3	1	12
Module status	1	1	1	1	1	1	1	1	1	1
Total measurements				**110,749**			**14,693**			**110,749**
Required test time				10 hrs			12 min			45 sec

Current-generation systems for T/R module testing are typically designed with an emphasis on measurement speed. Agilent has worked with our solution partners to offer total solutions that optimize throughput. The resulting systems can perform complete characterization of a T/R module with 100,000-plus measurements requiring an average test time of less than 45 seconds (Table 3). Depending on the mix of measurements, this latest-generation test platform can perform an order of magnitude more measurements in less than one-tenth the time required by the previous-generation test system. As a result, the overall speed improvement is approximately two orders of magnitude.

Depending on the number of channels in the module, the dominant factor in production test is likely to be the time required to load and unload the DUT. This constraint is minimized by an architecture that allows for loading the next DUT while the current DUT is being tested in parallel. An important implication is that there is no longer a benefit to making fewer measurements, as there is little or no increase in total throughput if fewer measurements are performed.

The current-generation platform uses Agilent X-Series instrumentation (Figure 3) while maintaining the advantages of the previous generation:

- COTS-based hardware and software simplifies ease of use and support
- Front-panel-based instrumentation (the latest standard) is highly suitable for engineering needs
- Test results correlate well with measurements performed in engineering (when using similar equipment)

Figure 3. When integrated into our solution partners' test solutions, X-Series instruments can perform an order of magnitude more measurements in less than one-tenth the total test time of prior solutions.

The latest-generation test solution is able to achieve dramatic throughput improvements by taking advantage of six key factors:

- Speed improvements in the instruments themselves due to numerous enhancements
- Highly optimized test algorithms that make optimum use of instrument capabilities
- Software that is designed with three capabilities:
  - Very low measurement overhead in calling test algorithms and managing data
  - Overlapped I/O with new measurements being made while the previous data is being retrieved
  - Overlapped measurements, with an architecture that allows measurements to be made simultaneously using different instruments
- Hardware-controlled DUT and instrument management that eliminates software latency
- Preprocessing of tests the first time the test plan is run (accelerates testing of subsequent devices)
- Simultaneous testing, loading and unloading of multiple devices

Engineering and production benefits

The ability to use standardized, COTS-based instruments to achieve extremely high throughput opens new capabilities to users in both production and engineering. For engineering, very high speed testing makes it possible to measure all module modes and parameters with fine resolution (looking for anomalies) in a few seconds. Engineers need not make compromises between fast turnaround and the quantity of data gathered. One positive consequence: This encourages more thorough testing of extreme conditions (e.g., temperature, shock and environmental) because the electrical parameters can be measured quickly relative to variations in those conditions. The large quantities of data gathered can also be used to improve component modeling.

For production, the most important improvement is in test time, resulting in a dramatic reduction in total cost of test. The ability to maintain the traceability of test results from engineering through each step in production has two benefits: it helps ensure delivery of a quality product, and it improves the production process by helping determine the sources of parameter variations. In addition, comprehensive testing reduces the risk of shipping a module with one or more anomalies. It also has the potential to improve yield through the use of narrower tolerance bands because all data points are measured. As a final benefit, comprehensive testing enables sorting and matching of modules to meet special needs, potentially at a premium price.

Summary

In the development of any test system, success depends on a changing mix of people and technology. As system technology becomes more complex, assuring readiness gets tougher. This can be especially true with radar, satellite and EW systems that utilize a wide variety of microwave and RF modules.

Today, T/R modules require extensive testing in both engineering and production environments. As the volume and complexity of T/R modules increases, measurement throughput becomes a major factor in the cost of test.

Agilent X-series instruments enable the latest-generation microwave test platform to provide throughput that is 100 times faster than previous generations. Test times—and the associated cost of test—are now approaching the time required to load and unload the DUT, making it feasible to take more rather than less data in production. The use of the same COTS instruments in both engineering and production ensures traceability of results across all measurements made on the product—from engineering through final production.

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