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Multiple TRM's Automated Measurement and Calibration Method of AESA Radar System in X-Band

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ABSTRACT

This paper presents an automated measurement and calibration algorithm for multiple Transmitter Receiver Modules (TRMs) in AESA (Active Electronically Scanned-Array) radar system in the X-band. The previously developed Automated Test Equipment (ATE) could only measure one TRM at a time, leading to reduced efficiency due to the need for repeated replacement and testing. Additionally, the previous calibration algorithm did not account for the error rate of the test jig. To address these issues, we simultaneously measured four TRMs to reduce testing time and improved calibration accuracy through a supplementary algorithm. We also added new measurement items such as In/Out delay time, pulse rising/falling time, spurious signals, Look-Up Table (LUT) generation through calibration, power consumption analysis and characteristic conversion results according to ambient temperature changes. A water-cooled chiller provided a uniform temperature environment for multiple TRM measurements and a user-centered GUI facilitated the addition and modification of measurement items. Our approach resulted in a 10.4% reduction in testing time compared to existing equipment and achieved results within ±1dBp-p and within ±5°of phase error through our supplemented phase/amplitude calibration algorithm.

Key Words : AESA, ATE, Calibration algorithm, Switch Matrix, TRM

Ⅰ. Introduction

The remarkable advancement of radar technology has led to the widespread use of active phased array antenna radar systems. Early radar systems used mechanically driven reflectors and passive phased array antenna structures, which had slow beam steering speed and were inefficient due to their centralized structure. If an RF transmitter/receiver failed, the entire antenna system would become inoperable. To address these issues, active phased array antenna systems were developed. These systems offer high-speed beam conversion and precise beam steering in response to complex wireless environments. They are also preferred for their miniaturization and lightweight design. By using multiple Monolithic Microwave Integrated Circuit (MMIC) amplifiers with relatively low transmit output power, the lifetime and reliability of the antenna system can be increased through a low failure rate and gradual deterioration without significant performance loss even if some elements fail[1]. Radar signals form a radiation beam in the desired direction and receive signals from targets using receiving beams consisting of a main lobe and side lobes[2,3]. The amplitude and phase change of Transmitter Receiver Modules (TRMs) are designed to achieve required beam formation and direction. Chapter 2 describes automated test equipment for TRM measurement and test methods for each item. Chapter 3 analyzes time reduction for single and multi-TRM measurements, presents result files,

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describes phase/amplitude correction algorithms, and presents pre- and post-correction results. Chapter 4 concludes the paper[4-6].

Ⅱ. System Analysis

This paper introduces multi-channel TRM automation equipment that is divided into test configuration and test items. This configuration allows for easy analysis of TRM T/Rx performance and design and manufacture of the upper system. Improvements over existing automated test equipment are described in sections 2.1 configuration of automated TRM measurements and 2.2 automated test items of TRM.

2.1 Configuration of automated TRM measurement

To perform automated TRM tests, it is necessary to identify the TRM configuration and test characterization for T/Rx. The cable assembly must then be manufactured according to each unit's test configuration. Fig. 1 shows a configuration diagram of four 16-channel TRMs consisting mainly of a transmitter and receiver. The transmitter includes a drive amplifier (DA), Pad, and high power amplifier (HPA), while the receiver includes a 2-stage low noise amplifier (LNA) and Pad. The phase shifter and gain adjuster for T/Rx are made up of a Multi-Function Chip (MFC), and a circulator is used for isolation between transmit output and receive input.

Fig. 2 shows the ATE configuration used for TRM measurement. It includes a test fixture that can hold four TRMs, instruments such as network analyzer, spectrum analyzer, signal generator, 64-channel switch matrix, power supply, chiller, switching hub, server and cable assembly. The ATE provides an automated control and measurement environment for four 16-channel TRMs with a user-friendly GUI[7,8] that allows all tests to be performed without changing test configurations. The GUI adopted C# as the basic language and is produced using the Windows Presentation Foundation (WPF) platform provided by Microsoft. It includes a function to continue or stop when a fail test item occurs during an automated test. It also generates test reports by inputting prior information such as size, weight and serial number of the TRM before testing and automatically collecting results after completion. A switch matrix is required for setting up control and automation measurement between TRMs and instruments for 64-channel T/Rx test paths. To improve measurement accuracy, a chiller maintains uniform temperature during testing. The in-house developed the Graphic User Interface (GUI) is user-centered with automatic monitor resolution optimization during operation.

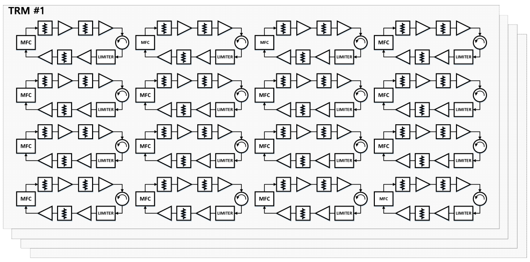
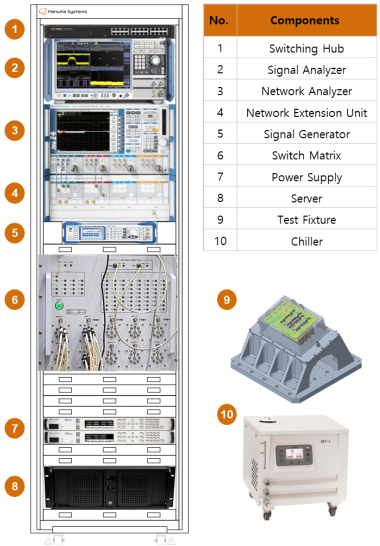


Fig. 1. Block diagram of 4-TRMs (64ch)



No.	Components
1	Switching Hub
2	Signal Analyzer
3	Network Analyzer
4	Network Extension Unit
5	Signal Generator
6	Switch Matrix
7	Power Supply
8	Server
9	Test Fixture
10	Chiller

Fig. 2. ATE used for TRM measurement

2.2 Automated test items of TRM

TRM automated measurement operation procedure is shown in Fig. 3. After launching the dedicated TRM GUI, instrument connections and power supply are checked through the GUI. If the instruments are not connected, you will need to check the Ethernet connection. When there are no issues found during inspection, the chiller is connected via USB for temperature control and equipment status checks. If the chiller is not connected, you will need to check the USB connection. After these processes are completed, instruments used for each test item are pre-calibrated. Transmitter Receiver Modules (TRMs) are then installed between test equipment and cooling plate and powered on to check connections before proceeding with automated testing. Instrument calibration involves four processes: Power calibration uses a power sensor to apply accurate power levels to the TRM; S-parameter calibration compensates for loss factors such as cables, switches and attenuators in T/Rx paths; Spectrum calibration measures loss of spurious, harmonics and pulse paths; Noise calibration uses a noise source to measure TRM NF (Noise Figure). If a failure occurs during automated testing, testing is stopped or other test items' influence is checked. After testing is completed, measured results are collected to generate a final test report. There are 20 items in total for TRM automated measurement tests as shown in Table 1. Test lists are divided into T/Rx parameters and common parameters. T/Rx Parameters include output power, pulse width, PRI (Pulse Repetition Interval), PRF (Pulse Repetition Frequency), duty cycle, pulse droop, pulse-pulse power ratio, pulse-pulse phase difference, OP1dB, NF and channel gain deviation

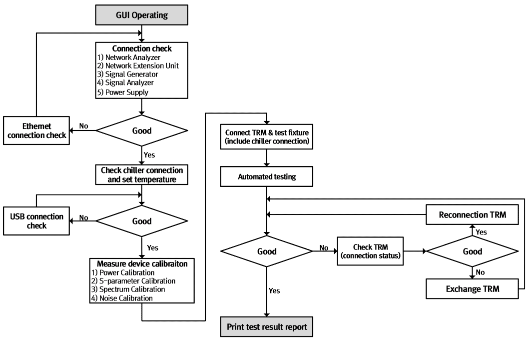


Fig. 3. Operating procedure of ATE

Table 1. Automated Test Measurement lists

T/Rx Parameter	Common Parameter
Tx Output Power	Harmonic
Tx Pulse Width	Spurious
Tx PRI, PRF	Gain
Tx Duty cycle	Phase
Tx Pulse droop	Attenuation
Tx Pulse-Pulse power ratio	VSWR
Tx Pulse-Pulse phase difference	Pulse rising/falling time
Rx OP1dB	In/Out delay
Rx Noise Figure	Power consumption
Rx channel gain deviation	LUT

while common parameters include 2^{nd} and 3^{rd} harmonic, spurious, gain, phase, attenuation, VSWR (Voltage Standing Wave Ratio), pulse rising/falling time, In/Out delay time, power consumption and LUT.

Ⅲ. Experimental Results

3.1 Automated TRM measurement efficiency

Manual TRM measurement requires many test procedures such as changing test configurations for each test item and changing cables for each channel. This increases measurement time and varies depending on worker skill and environment. The automated measurement method described in this paper eliminates the need for separate test configurations or cable changes for each channel, reducing manual measurement time and providing uniform measurement times. Existing automated test equipment was designed to automatically measure four TRMs simultaneously to reduce time by measuring one TRM at a time and taking another after testing is completed. Based on Table 1's test items, an average of 16 manual measurements took about 12 hours per session. Automated measurement reduced this to 3 hours and 10 minutes per session based on 16 sessions, saving about 73.6% of time. Additionally, automating one TRM at a time took 14 hours and 20 minutes while automating four TRMs simultaneously improved performance by an additional 10.4% with a time-saving efficiency of 12

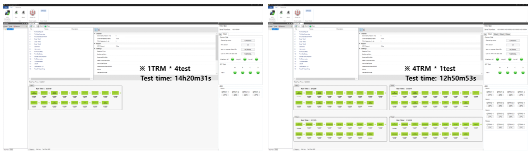


Fig. 4. Comparison result of 1-TRM & 4-TRM test-time

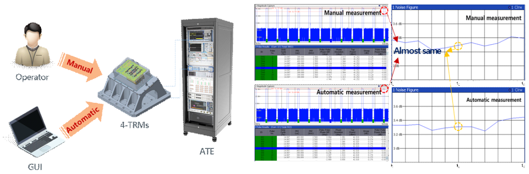


Fig. 5. Comparison result of Manual & Automatic

hours and 50 minutes. Fig. 4 shows cumulative measurement times for one TRM and simultaneous measurement times for four TRMs using the automated measurement GUI. Fig. 5 compares a manual and automatic Tx output measurements and Rx NF within instrument error accuracy. In can be confirmed that both manual and automatic measurements are satisfied in the transmission output 40dBm specification, and it can be confirmed that the deviation between each output is within 0.2dB. In the case of the received NF, spurious and harmonics, it can be confirmed that similar measurement results are obtained. As mentioned in the paper, the act of measuring multiple Transmitter Receiver Modules (TRMs) at once has the hardware efficiency of mounting and detaching a single TRM,

3.2 TRM phase/amplitude calibration algorithm

Manual TRM measurement requires many test procedures such as changing test configurations for each test item and TRM phase/amplitude calibration algorithm is shown in Fig. 6. It generates a default align LUT from the FPGA by creating a 6-bit by 6-bit matrix based on measured phase/amplitude values before calibration. Phase and amplitude values measured through the GUI are set to calibration values within 1 bit of phase (5.625°) and 1 bit of amplitude (0.5 dB). These values are stored as final LUT in flash memory. In the LUT stored in the form of a 64x64 matrix, a row corresponding to

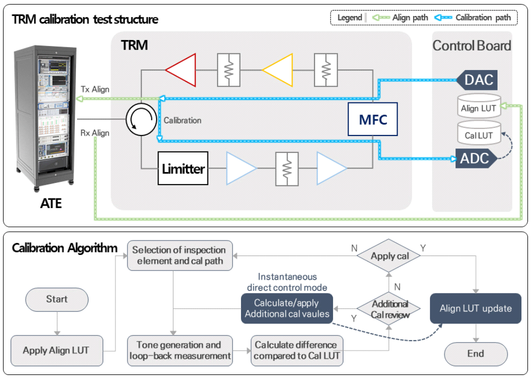


Fig. 6. Calibration test structure and algorithm

phase value 1 is found, and the attenuation value in phase value row 1 is varied by 0.5dB units from 0 to 31.5dB, and the measured data is composed one by one and calculate the difference between the stored align data and calibrates it.

Within the digital control system, cross-coupling errors for phase/amplitude values are reduced as much as possible through a calibration algorithm using MATLAB code. Fig. 7 shows phase/amplitude results before and after calibration with a confirmed phase error of ±5° and an amplitude error of 1dBp-p [9,10].

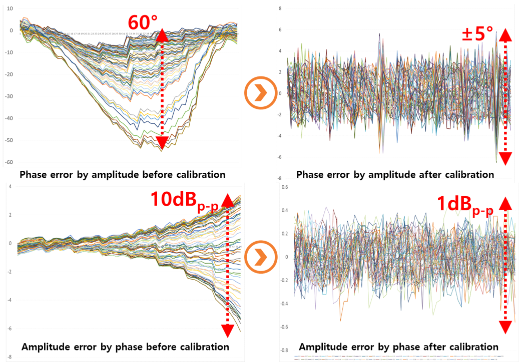


Fig. 7. Before and after calibration result

Ⅳ. Conclusion

Recently, in a situation where the demand for active phased array antenna system is explosively increasing, efficient production of TRMs, which is a key component, and reduction of test time are essential. In order to meet these requirements, Automatic Test Equipment (ATE) production is required, and it does not end with automated measurement, but a one-button execution GUI is designed and produced, including real-time pass/fail determination of all test items and generation of test result reports for all test items after the end of the test.

This paper describes a TRM automated measurement test method and phase/amplitude calibration algorithm for active phased array antenna devices. TRMs are key components of massive array antennas and require efficient productivity and reduced test times. To meet these requirements, ATE production and a one-button execution GUI are essential for generating required test items and test result reports. The ATE produced in this paper demonstrated production efficiency and time reduction through automated measurement and correction of four 16-channel TRMs. User-centered environment was established by adding detailed items such as In/Out delay time, pulse rising/falling time, spurious signals LUT generation through calibration power consumption real-time inspection of test items and instrument status. Performance of previously designed and manufactured ATE was improved to increase production efficiency and improve calibration accuracy. Unnecessary incidental maintenance time was reduced by 10.4% from existing 16-channel single-unit TRM tests to simultaneous four-TRM tests with results within ±5° and ±1 dBp-p obtained through the supplemented phase/amplitude calibration algorithm.

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