# New Challenges for Low Cost and High Speed RF ATE System

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## Abstract

This paper presents the implementation of the low cost and high speed RF ATE(Automatic Test Equipment) system, which can be a reasonable solution for reducing the test cost of RF devices. This paper suggests high speed and precise measurement capabilities which are realized by the 16 independent RF ports with high speed switching time and high accuracy digitizer using the industry standard Versus module eXtensions for Instrument(VXI) and General Purpose Interface Bus(GPIB) interfaces. Also, the system has the capabilities of quad-site test, which can dramatically increase the device throughput. This paper concludes with the demonstration of the implemented ATE system through the setup of RF Power Amplifier Module(PAM), which is under the most competitive market situation.

## 요 약

본 논문에서는 RF 소자들의 테스트시 비용 절감을 극대화 할 수 있는 저가형 고속 RF 자동화 테스트 시스템(Automatic Test Equipment, ATE)의 제작에 관하여 다루어진다. 제작된 RF ATE는 고속의 스위칭 시간과 고정밀 디지타이저를 포함한 16개의 독립적인 RF 입출력 단자를 갖고 있으며 산업 표준인 VXI(Versus module eXtensions for Instrument)와 GPIB(General Purpose Interface Bus) 인터페이스를 사용하여 구성된다. 또한 소자의 생산효율을 극대화하기 위하여 동시에 4개의 소자를 테스트할 수 있도록 시스템이 구성된다. 마지막으로 현재 가격 경쟁이 상당히 심한 소자 중 하나인 RF 전력증폭모듈을, 제작된 RF ATE를 이용하여 테스트를 진행하여 시스템 성능을 검증한다.

Key words : ATE, Test, Receiver, PAM, VXI

## Ⅰ. Introduction

With the growth of the wireless communication market, most of RF device manufacturers have been under the cost pressure with the appearance of many companies in the same field. In order to find the solution of this problem, it has been focused to reduce the overall process cost, such as package assembly, final electrical test and etc. Especially, the functional test has been unavoidably needed the high-priced ATE system to satisfy the quality and throughput of the requested devices by many customers. In this aspect, the cost reduction in test area has been considered as one of the most difficult issues.

RF ATE system should be guaranteed to keep the reliability for the test measurement values including the repeatability and reproducibility because it is very important to test the devices without any errors[1]. In the same time, it could be constructed by the high-speed controlled hardware to minimize the electrical test time,

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which will be a very big opportunity to increase the production throughput and save the overall process cost. The RF ATE system design presented in this paper has been focused on the reliability, measurement speed, low cost investment and easy approach to maintenance. Bellow is some of the challenges and considerations in order to design RF ATE system.

1. Selecting the appropriate system communication bus.
2. Constructing the reasonable and speedy up-conversion blocks and source driver, which have been designed to reduce the frequency, amplitude and mode switching time while supporting other crucial specifications.
3. Designing a low cost RF receiver to obtain the precise and high-speed data acquisition.
4. Developing a solution for stabilized RF and DC connection.
5. Accomplishing the automated system control

Through the flexible hardware and software design, this system introduced in this paper replaces several high-priced microwave bench instruments such as a microwave CW signal generator, a power meter, a frequency counter, a spectrum analyzer and a vector network analyzer.

## Ⅱ. Selecting the System Communication Bus

Designing and selecting the main system bus is one of the most difficult parts of the system design procedure. Because this system focuses on the cost reduction and high-speed reaction rate, it was decided to use commercially available bus architecture like GPIB, VXI and PCI eXtensions for Instrumentation(PXI).

In the legacy test system, most of the RF turn-key instruments had the built-in GPIB. Even though some brand new GPIB interface supports over 7.7 Mbytes/sec I/O speed, most of the equipments still use the standard IEEE 488.1 3-wire handshake protocol and only shows 900 Kbytes/sec maximum speed. This limited and slow bus speed lowers the overall performance of the test system. Another consideration is PXI. The PXI specification defines a rugged PC-based platform for measurement and automation systems. But, in the aspect of RF measurement no specifications defined for Electro-Magnetic Interference(EMI) / Radio Frequency Interference(RFI) yet. So there is still high probability of adjacent instruments interfering with each other. Finally, VXI is one of the mainstreams in bus architecture of ATE systems. The VXI platform was designed by instrument manufacturers and users specifically to meet the needs of the modular instrument market. It is a stable, reliable standard, with field-proven interoperability, power, and cooling specifications. Also, all manufacturers provide shielded modules, which ensure interoperability between equipments.

Because this ATE system focuses on fundamentally RF devices test, VXI was chosen for the main system bus in the aspect of system reliability and gauge performance. For slot 0 interface, MXI-2 bus interface was used to maximize the data transfer rate up to 38 Mbytes/sec. Also, other kinds of bus systems were used like GPIB, PXI, LNA, USB, RS-232C and Firewire as required on the each instrument in this RF test system (Fig. 1).

## Ⅲ. Design of the High-Speed Switching RF Source

Currently, most of the RF equipments are more expensive than others like the digital or dc equipments, but the operation speed of the RF equipments are slowrelatively. In case of traditional RF signal gene-

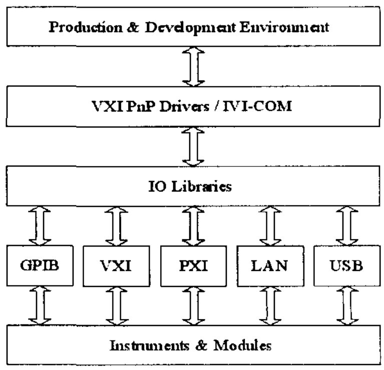


Fig. 1. System bus architecture.

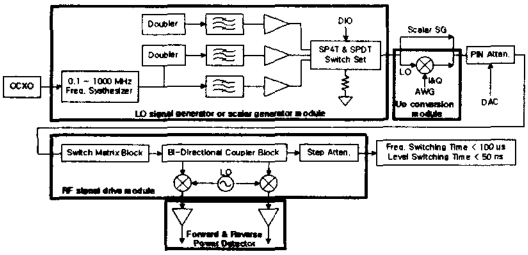


Fig. 2. Block diagram of a RF signal generator.

rators used at the test laboratory, the operating frequency range, RF power level, stability and phase noise has been regarded as the most important specifications. In order to satisfy high speed ATE configuration, it is critical to additionally consider the frequency, amplitude, and mode switching time, which mainly affect a total test time. In this system, eight RF signal generators have been accomplished by using a fast switching LO synthesizer and the RF signal drive modules which is composed by the voltage variable attenuators and the solid state GaAs switch matrix. It is connected to a step attenuator, a high power amplifier, a circulator and a bi-directional coupler as shown in Fig. 2.

The electronic switch matrix supports the RF synthesizer to have a various capacity such as two and three-tone combined source, the split source and the path alternation. Therefore, the mode switching time gets actually fast as the behavior speed of the GaAs switches. While designing the RF source driver boards, it was constantly observed and concerned to avoid the distribution of unwanted noise and the interference between each signal. It is the isolation characteristics, which is very potential point to optimize the design of the switch matrix. In order to exclude the disadvantages of the electric switches, the only method is that the mechanical switches would replace it. However, the mechanical switches have a big weak point that is the short lifetime relatively, which is one of the most important specifications in the production floor. It is directly related with the maintenance, which affects the utilization of the production line.

The voltage variable attenuator included in the RF source drive boards is controlled by the VXI modular Digital to Analog Converter(DAC). First of all, it provides the possibility of the high speed RF level change in our system. However, because it has a narrow attenuation range, it has unavoidably been connected to the step attenuator which has about 130 dB attenuation rage normally.

The bi-directional couplers are the important component for the measurement of forward and reverse power. It has been directly connected to the automatic gain control amplifier and the precision logarithmic amplifier which is to convert the RF power to DC. The converted DC level is easily measured by the VXI controlled voltmeter or digitizer.

Another consideration on our test system configuration is the generation of the modulated stimulus signal. In order to generate these signals, the arbitrary waveform generator has been used with the IQ precision IF to RF conversion equipment which has been controlled by GPIB bus and supported the external IQ connection. This configuration has a big advantage to reduce the required cost to purchase the vector signal generator and can make the required modulation signal except some ones. Also, it can provide the probability to extend test capacity such as Bit Error Rate(BER) and Error Vector Magnitude(EVM) measurement[2]. Through the receiver architecture and software algorithm, the BER and EVM test can be constructed without the high-priced specialized instruments.

The system presented in this paper has the capabilities of the quad site test which need the sufficient RF scalar source without any interferences. It has been accomplished with the flexible design and construction which includes the up-conversion mixer, fast LO source and RF drive block. Also, the source for the modulation signal would be supported in this system with low cost and high speed configurations.

## Ⅳ. Design of the Precision RF Receiver

Most engineers use generally the power meters or the spectrum analyzers to measure the RF parameters such as output power, ACPR and etc. However, there are some problems to apply them to ATE because they were generally fabricated for the engineering bench test. Especially, the weak points of these equipments are related with the switching time such as the frequency, level and mode conversion time. Also, it is obvious to have the disadvantages of the purchasing price and the measurement speed except the measurement capability. Above all things, it is very difficult to access the high volume data from the bench equipments because some bench equipments are still controlled and supported by the low speed communication bus like GPIB. Therefore, some test systems constructed by the bench equipments have normally more than two spectrum analyzers and signal generator to obtain the minimized test time. However, it is clear that there is a limitation. Also, this method brings the shortcoming to make slow on the system communication bus speed and complicate to code the test program. First of all, the expense of the test system construction is spontaneously become bigger than the initial estimation.

To overcome everything, it is necessary to have the fast bus system that can acquire large amount of data in a short moment. It made this test system to select the VXI equipments which have the characteristics for the stable and high-speed communication bus.

As above considerations, the frequency, level and mode change time is potentially important to reduce the total test time. The presented system tries to find the solutions of the test time reduction through the challenge of VXI module, Fast Fourier Transform(FFT) algorithm[3], RF drive board and fast switching LO source. The receiver configuration of our system is as Fig. 3.

First, it was not used RF equipments of high price like the spectrum analyzer and the power meters. Instead of that, the Analog to Digital Converter(ADC) and FFT algorithm were constituted in order to measure all of the RF characteristics[4]. In addition to the improvement of the repeatability and reproducibility which

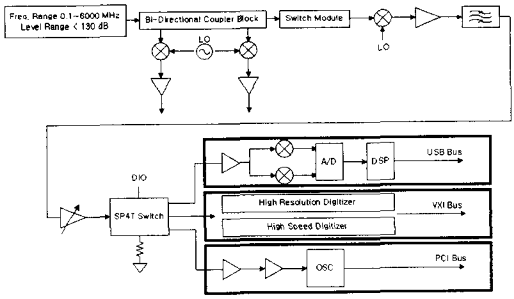


Fig. 3. Block diagram of a RF signal analyzer.

represent the gage R&R, this system would be used the high resolution of 23 Bit ADC controlled by the VXI communication bus. The measurement deviation is about +/ - 0.03 dB which is reasonable in the test production floor.

Second, the receiver drive boards are designed to minimize the conversion time, for example the level and mode switching time. These boards including the RF electronic switch, high pass filter and variable attenuator would be fabricated in the test head to dramatically reduce the length of RF path. Therefore, only the analog and DC signal flows through the relative long cables between the main test system and test head. It brings the enormous effect to minimize unwanted noise and interference which makes it difficult to do the correlation between the bench and production test. All of RF drive boards would be shielded under the EMI/RFI considerations.

Third, the frequency switching time of the LO source plays the very important role in the test on the RF characteristics and it is not too much to say that the speed performance of the system depends upon it. The phase noise performance is one of the most important specifications with the frequency switching time while selecting the LO signal generator. If the characteristic of the phase noise is getting worse by the external circuit effects such as the noise figure of the power amplifiers and the electronic switches, the dynamic range of the test system become narrow[5]. In the case of external circuits, it would be designed with the consideration of the noise figure to maintain the characteristic of the phase noise on the LO signal generator. And, this system used the LO signal generator with the Direct Digital Synthesis(DDS) option. Therefore, it is currently good method to be satisfied the RF characteristic and the frequency switching time of microsecond at the same time.

## Ⅴ. Development of the Stabilized Connection

For Quad site test, it needs many RF ports, DC and digital lines. Because the test head would be separated from main system, all ports and lines have to use the proper connection method. However, the connection areas always make the difficult production condition. And the improper contact methods, the repeated movements and the unknown vibrations cause the unstable system condition, various losses, unnecessary contact resistance and the repeated system maintenances. In order to make the exact sourcing and measurements, the total number of the contact points must be reduced. Also, the proper arrangement of the ground pins is very important to make the high quality source and the measurement.

The DC and digital lines use only two connections from the exit of main system to device under test (DUT) board. Also, each RF lines use two connections from the end of the main system to RF switch units in the test head. No cable connection was used between the test head and DUT boards. For RF connection, the RF blind-mates with low loss were used. To minimize the interference of each port, the RF receiver ports are separated from the RF source ports. For DC and Digital connection, the spring probes with very low contact resistance were used.

To dock easily the DUT board to the test head, the mechanism of the cam-follow bearings were used. The engagement force of blind-mates and the compression force of many spring probes are supported by a few bearings. Due to the mechanism of the bearings, the DUT board can be docked easily at the test head with very small force. To realize exact contact between them, the accurate alignment was requested. To align exactly, the test head had two alignment pins and the DUT board frame had the alignment holes for the alignment pins. The proper connection method and the docking mechanism between the DUT board and the test head play an important role to the system condition and the system maintenance period.

## Ⅵ. System Programming

The system program was designed in the point of three groups: operators, process engineers and development engineers. In this aspect, the program is separated by the three sections: test, development and maintenance. And the most of the test systems are usually used in the production environment and operated by the production operators, it is very important to accept the requirement and request of the operators and technicians.

Below are the considered subjects for designing the system program.

- Fool-proof production environment
- Form-based environment
- Remote System Monitoring Function through Web
- Remote control of the system through Web
- One-click measurement setup

In production environment, there are a lot of mistake occurred by the production operators. For example, when entering the lot number by using the bar-code scanner, another character can be added in front of or at the end of the lot number by unintentional stroke of the keyboard. Even though all the operators are well trained and are asked to do the double check of the input data, this kind of problem can be happened any time. In this aspect, a kind of fool-proof system is used to prevent entering unintentional characters at the lot number input text box. If the operator inputs the lot number in any way, the program measures the elapsed time of the entered characters. Then the program justifies whether the lot number was entered by the bar-code reader or manual stroke by the operator. Another important aspect of the test program is that all the user interface is consisted of the form-based intuitive environment like 'click and run'.

Operator's environment is separated in two sections: test summary and test parameter windows. These days, devices are becoming more complex compared to the yesterday's ones. So the total number of test parameters is greatly increased to hundreds and thousands. In consequence, the system speed is getting lower by displaying all the test parameters to the monitor if the parameters result sharing the display window with test summary. Also, for the convenience of the operators, a lot of statistic data was added to the summary window like total yield, yield trends between input counts and pass-fail flag.

In the process engineer's view, it is very important to monitor the current status of the test system and make a right decision as soon as possible. To help this kind of task, web monitoring capability was added to the system. They can monitor the current status of the system like running status, system utilization and system failure mechanism. Another important capability is the remote control of the system through the web, which is at the final stage of the development by using ASP.NET technology.

For the test development engineers, a lot of helpful development environment were added to the program like one-click measurement setup. From the old legacy rack & stack system we could get all kind of test solutions and those were merged to this new test development environment. Most of the test parameters were built in the library and 'one-click' measurement setup can be possible.

In the previous test program of our legacy rack & stack system, it was impossible to support the test data files like Standard Test Data Format(STDF) and ASCII Test Data Format(ATDF). In this release, STDF, ATDF and Comma-Separated Values(CSV) file format are basically supported. Also, automated web reporting system is under development. So, one who has a right to access the system can see the test data log through the web without the help of separate IT team.

## Ⅶ. System Conformation through RF Power Amplifier Testing Application

In order to verify the performance of the test system, a RF PAM that has been produced at our company was selected. And the measurement data were compared with the data that measured with the bench equipments. Also, the stabilization was checked through the test of repeatability and gauge capacity. This PAM could be used at the tri-bands, GSM, DCS and PCS. Bellow is the test sequence on the parameters.

1. Output power, current and stress test
2. Output power, current and PAE measurement
3. Power down nano-current measurement
4. Cross-talk power measurement
5. Power down current and output power measurement
6. Output power and current measurement on the input power off state
7. Second and third harmonic measurement
8. Gain slope measurement in the variation of the control voltage

All parameters above were tested at all bands(GSM, DCS and PCS) and the total number of the parameters is 108. The test result at the system presented in this paper is below.

First, repeatability exercise was performed between two systems for 100 times with the same unit. The compared system is currently running for the PAM production. As can be seen in the Table 1, the current and the power measurement capability are accurate as shown in the comparison table. In this measurement, handler, contact pins and docking variance were excluded by hand test mode to see the tester itself performance. And the measurement from the new system was done before correlation exercise so there is average difference between a conventional ATE and this new system introduced in the paper.

Second, the Gauge R&R exercise was performed with the same test condition, load board, contactor and

Table 1. The results of the repeatability exercise.

GSM Band

| ATE | Idd_3.5 V_915 | Pout_3.5 V_915 |
|---|---|---|
| Average | 1.6430 | 34.8995 |
| Stdev | 0.0010 | 0.0281 |
| Max. | 1.6504 | 34.9644 |
| Min. | 1.6419 | 34.8530 |
| Range | 0.0085 | 0.1114 |
| New System | Idd_3.5 V_915 | Pout_3.5 V_915 |
| Average | 1.7083 | 34.2440 |
| Stdev | 0.0003 | 0.0062 |
| Max. | 1.7101 | 34.2586 |
| Min. | 1.7078 | 34.2276 |
| Range | 0.0024 | 0.0310 |

DCS Band

| ATE | Idd_3.5 V_1747.5 | Pout_3.5 V_1747.5 |
|---|---|---|
| Average | 2.0352 | 34.0022 |
| Stdev | 0.0072 | 0.0468 |
| Max. | 2.0928 | 34.1822 |
| Min. | 2.0299 | 33.9334 |
| Range | 0.0629 | 0.2488 |
| New System | Idd_3.5 V_1747.5 | Pout_3.5 V_1747.5 |
| Average | 1.5147 | 33.4673 |
| Stdev | 0.0004 | 0.0069 |
| Max. | 1.5164 | 33.4964 |
| Min. | 1.5138 | 33.4466 |
| Range | 0.0026 | 0.0498 |

PCS Band

| ATE | Idd_3.5 V_1880 | Pout_3.5 V_1880 |
|---|---|---|
| Average | 1.8001 | 34.0697 |
| Stdev | 0.0017 | 0.0441 |
| Max. | 1.8049 | 34.1549 |
| Min. | 1.7974 | 33.9798 |
| Range | 0.0075 | 0.1751 |
| New System | Idd_3.5 V_1880 | Pout_3.5 V_1880 |
| Average | 1.5278 | 33.2336 |
| Stdev | 0.0002 | 0.0097 |
| Max. | 1.5282 | 33.2586 |
| Min. | 1.5272 | 33.2096 |
| Range | 0.0010 | 0.0490 |

10 units for the key parameter. The result showed a preferred result of below 5 %, so the system can be used for the production.

Finally, one production lot was tested on both production system and this new one after correlation exercise with the bench instruments. The test condition is same with test plan, load board, contactor and units. The production lot was tested at the new tester first and the categorized units were retested at the production tester. The result is that all the good and reject units from the new tester were categorized as the same at the production system(Fig. 4).

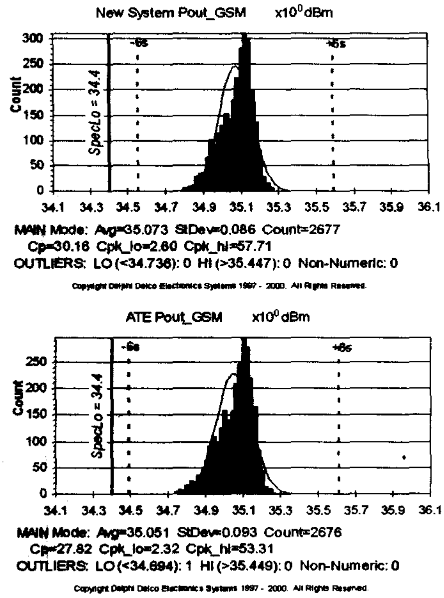


Fig. 4. Distribution of GSM output power.

According to this verification result using a production lot, it was confirmed that the new tester can make the production lot sort accurately and better throughput compared to the currently available production tester.

## Ⅶ. Conclusions

Our RF test system presented in this paper has been focused to minimize our budget and maximize the throughput to give satisfaction to many customers.

First, while it would not purchase the high cost RF instruments to minimize the total cost of our tester, the up and down converter is directly designed and constructed as the practical application of the relatively low cost analog and digital equipments. Through these works, the total budget required to fabricate RF tester is dramatically reduced.

Second, in order to maximize the throughput in the production environment, this paper would introduce some reasonable requests: a high speed communication bus system, a proper RF source, a receiver and a LO source with the fast switching time.

At the same time, our RF test system would be satisfied to get the low cost and high-speed solution with the reasonable test results and performance through the correlation between our RF tester and the bench equipments, and the gauge R&R capabilities.

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