Design of an Automatic Test System for Power Amplifier Modules

Huang Xin-cheng 1*, Tian Hong 2
1 College of Electronic and Information Engineering, Nanjing University Of Aeronautics And Astronautics, Nanjing, Jiangsu, 210000, China
2 College of Electronic and Information Engineering, Nanjing University Of Aeronautics And Astronautics, Nanjing, Jiangsu, 210000, China
* Corresponding author’s e-mail: zhangjd@nuaa.edu.cn

Abstract. This article introduces the design of a power automatic correction system for radar transmitter power amplifier modules. The system is mainly composed of a control computer, a test bench, a fault detection unit, general instruments and apparatus, and a GPIB interface card[1-2]. The article describes the working principle, test process, and test method of this system in detail. The actual test shows that the system can effectively improve the power calibration accuracy and significantly improve the debugging efficiency.

1. Introduction
In the past radar system, power amplifier modules, as the core of radar transmitter, usually display just two states (normal or failure). This detection method is relatively simple and inaccurate. If the threshold range is narrow, it is easy to produce false alarms. Conversely, if the threshold range is wide, the module state cannot be accurately determined, and it is easy to cause misjudgment of the fault. With the development of radar system and the requirement of radar health management system, radar monitoring system needs to accurately obtain the output power value of power amplifier modules for fault analysis and state prediction.

This article will describe an automatic calibration system for power amplifier modules in detail. The system has the characteristics of anti-interference, multi-parameters, high accuracy, and broadband. It is suitable for power amplifier module power calibration testing, module performance testing, module maintenance[3-4], radar health management and other application scenarios.

2. Principle of power monitoring
The basic principle of power monitoring is: a fault detection unit in the power amplifier module reads the power amplitude analogue-to-digital conversion value (AD value for short, the same as below) which coupled to the output terminal in real time, and fits it with the module actual output power value (P for short, the same as below) measured by the instruments and apparatus, and then calculates the power correction coefficient. When the module is working normally, the fault detection unit can obtain the internal AD value, and read the corresponding power correction coefficient according to the working mode, working temperature, working frequency and other factors, and then reverse calculate the current power value.

As shown, the key point of power amplifier module power calibration is the matching degree between the internal AD value and the actual output power. The higher the matching degree of correction
coefficient is, the closer the power value calculated by the module is to the actual output power. The simplest treatment is linear fitting, such as $P=K\times(AD)$, where $K$ is the power correction coefficient. In actual use, affected by factors such as different chips, operating conditions, temperature, interference, etc., the actual power value $P$ and AD value at the same frequency is not a simple linear relationship. In order to better characterize the relationship between them, it is necessary to read the internally detected AD value and actual output power value in multiple scenarios, which are used to calculate and analyse the correction coefficient. In order to ensure the accuracy of the data during actual operation, the correction coefficient is calculated by curve fitting.

3. **Manual test and automatic test**

The basic principles of manual test and automatic test are the same, the main differences are as follows.

3.1. **Manual test**

The general steps of manual test are: instruments and apparatus calibration $\rightarrow$ test system connection $\rightarrow$ data acquisition record $\rightarrow$ data post-analysis $\rightarrow$ power correction coefficient configuration $\rightarrow$ module debugging verification, etc.

In order to obtain as much test data as possible, it is necessary to constantly change test conditions manually to ensure the accuracy of correction coefficient. Since the output power of each frequency in working frequency band of the power amplifier module cannot be completely consistent, different modules and different working conditions also make different result, it is necessary to test the working frequency of each module one by one when performing power calibration, which will generate a lot of collected data for post-analysis. With a large amount of repetitive testing and calculation work, manual testing will inevitably introduce errors. If an error is found, it needs to be re-calibrated and tested, which is time-consuming and seriously affects the debugging efficiency of modules.

3.2. **Automatic test**

Through the analysis and research of manual test methods, the repetitive work content can be replaced by an automatic calibration system composed of a dedicated test bench, a computer and various test instruments.

The test method is as follows: the automatic test system controls instruments, the test bench and power amplifier module by computer. After self-test and initialization of the instruments, the test bench simulates the different working state of the transmitter and generates different test triggers to the signal source generator and the power amplifier module. When power amplifier module works stably, the computer reads module output power and internal AD value of the module, stores these data in a one-to-one correspondence. After recording, the computer switches the signal source generator output power or frequency and repeats above steps.

When the test data collection of all frequency points is completed, computer will calculate the power correction coefficient of the module at each frequency point through data analysis and curve fitting, and then send the correction coefficient to power amplifier module as dedicated correction coefficient of the module. After all those, computer will automatically execute a power closed-loop test. The block diagram of the automatic test system is shown in Fig 1.
Fig 1. Diagram of automatic test system

4. Hardware design
The hardware design mainly includes bus selection, detection circuit design, anti-interference design, etc. The detailed design is as follows.

4.1. Bus selection
Commonly used instrumentation buses include PXI, GPIB, LXI, etc. Among them, the PXI bus tends to be customized, specialized, and large-scale. The general-purpose interface bus GPIB is a bus that connects devices and computers. Most desktop instruments can be connected to computers through this interface. LXI is a modular test platform standard based on local area networks. It combines the high performance of GPIB instruments, the small size of PXI instruments, and the high throughput of LAN. In this scheme, considering factors such as software development scale, development cost and existing interfaces of instruments, the GPIB bus with high performance, low cost and low development risk is selected as the development bus, and other bus types are developed in similar ways.

4.2. Detection circuit design
The power monitoring of power amplifier module is mainly completed by a fault detection unit inside the module. The RF output signal of the module is input to the fault detection unit after passing through a coupler and detector. The fault detection unit's partial detection circuit is shown in Fig 2.

As shown in the figure above, the A terminal is the detection level input terminal, and the C terminal is the detection level output terminal through the negative feedback operational amplifier circuit. After the detection level is amplified, it is sent to AD module for analogue-to-digital conversion. According to the negative feedback circuit, formulas (1) ~ (2) can be obtained.

\[
\frac{U_{IN}-U_1}{R_5} = \frac{U_o-U_{IN}}{R_2} \quad (1)
\]

\[
\frac{U_{REFOUT}}{R_3+R_4} = \frac{U_{IN+}}{R_4} \quad (2)
\]

Formulas (3) and (4) are calculated from formulas (1) ~ (2).
The actual design is as follows: $R_2=33.33\, \text{K}\Omega$, $R_3=2\, \text{K}\Omega$, $R_4=1.8\, \text{K}\Omega$, $R_5=22\, \text{K}\Omega$, substituting the formula to get:

$$U_o = 2.97 - 1.5U_i.$$  \hspace{1cm} (5)

The effective input level of the AD chip AD9064 is $2V\sim3V$, and the internal detection level input range of the power amplifier module is $U_i \in (0,600mV)$. The detection circuit can meet the input dynamic range, and the 8-bit AD output can also meet the accuracy requirements for use.

4.3. **Anti-interference design**

The fault detection unit in the power amplifier assembly works in a strong electromagnetic radiation environment, signal sampling and transmission may be interfered. Therefore, the automatic test system adopts a variety of anti-interference processing measures in the design to ensure the stability and accuracy of the data. To solve the interference problem caused by signal sampling, in addition to strengthening the shielding property of fault detection unit, abnormal data removal, smoothing and normalization processing are also carried out for AD data collected to ensure the accuracy and reliability of AD data. In terms of data transmission, CAN bus with strong anti-interference ability is adopted, and message data verification bits are added to ensure reliable data transmission. Because of the above anti-interference processing, the bit error rate of data can be greatly reduced, and the accuracy of computer recorded data can also be greatly improved, thus providing guarantee for the accuracy of subsequent correction coefficient.

5. **Software design**

The automatic test system controls signal source generator, RF power meter and the test bench separately through the computer to obtain the real-time power and the corresponding AD value. A single frequency is calculated by using the method of least square curve fitting (other algorithms can also be used as required) to obtain the power correction coefficient at this frequency. By switching signal source generator frequency and repeating above steps, the power correction coefficient of power amplifier module in its frequency band can be obtained. When automatic correction is completed, computer sends...
the correction coefficient and stores it in the corresponding fault detection unit. The processing flow of automatic correction software for power amplifier module is shown in Fig 3.

Fig 3. Software flow chart

Step 1 (interface device initialization):
The computer initializes the test bench, signal source generator, RF power meter and so on, and checks the working state of each instrument.

Step 2 (automatic calibration test):
When step 1 is completed, the computer controls test bench and signal source generator to generate excitation signals. When the power amplifier modules work stably, the fault detection unit obtains the internal AD value and transmits it to the computer in real time. The computer performs data smoothing and normalization. At the same time, the computer obtains the value of the RF power meter through the GPIB bus, records the AD value of the current frequency and the measured power value. It can also record the corresponding AD value under different output powers by adjusting the output power of the signal source generator. Repeat the above steps until the last frequency in the frequency band.

Step 3 (correction coefficient calculates):
When the full frequency band test of a single power amplifier module is completed, the computer will curve-fit the recorded AD value and power value to generate the correction coefficient. The correction coefficient is sent by computer to the fault detection unit. When radar transmitter is working normally, the fault detection unit calculates current power according to the AD value, and sends it to the radar monitoring system in real time.

Step 4 (verification of calibration results):
After step 3, the working test is performed. The power amplifier module works in the transmitter, and the difference between the calculated power value and the actual output value is compared to calculate the current correction accuracy, so as to ensure the accuracy is within the index range.

6. Practical application
By comparing the results of manual test and automatic test of two power amplifier modules in the same batch under the same test conditions, you can intuitively see the advantages of the automatic calibration system.

The power amplifier module works normally in the transmitter. The actual power value of the power amplifier module is measured, the calculated power value of the module is read synchronously, and two sets of data are recorded at the same time. The results of manual test and automatic test are shown in Fig 4, Fig 5 and Table 1.

![Manual test result diagram](image)
![Automatic test result diagram](image)

### Table 1. Data Comparison (based on power value 2200)

|                       | Maximum Permissible Error (MPE) | Mean Absolute Error (MAE) | Root Mean Square Error (RMSE) | Mean Absolute Percentage Error (MAPE) |
|-----------------------|---------------------------------|---------------------------|------------------------------|--------------------------------------|
| **Manual**            | -408                            | 49.52                     | 88.12                        | 1.31%                                |
| **Automatic**         | -50                             | 10.22                     | 12.28                        | 0.29%                                |

The abscissa in the figure represents the frequency of the test, and the ordinate represents the measured value and the calculated value of the power. It can be seen that the automatic test is better than the manual test in sampling data processing accuracy and correction coefficient matching.

In addition, manual intervention is required for signal source generator parameter setting, data synchronization recording, data fitting, closed-loop testing and other work in the manual test state. Some operational steps also require the cooperation of multiple people. After adopting the automatic test system, only one person is required to operate, which not only reduces the working intensity of personnel and reduces the man-made faults, but also improves the calibration efficiency and ensures the calibration accuracy.
7. Conclusion
The automatic power correction system of a radar power amplifier module studied in this paper makes full use of the fast computing and processing capacity of computers, which greatly improves the test correction speed. Meanwhile, it can be applied to modules of different frequency bands by changing the configuration of the dedicated test bench. This system has good versatility and scalability, and can be used as a general test platform.

Acknowledgments
Many people have offered me valuable help in my thesis writing, including my tutor, classmates and workmates. I would like to express my gratitude to all those who helped me during the writing of this thesis.

References
[1] Wang Jiangbo, Lan Yonghai, Lv Jian (2003) A power amplifier automatic test system. Communications Countermeasures, Vol.32, No.4:15-18.
[2] Du Jv, Yan Maode (2003) Development and application of radio frequency module automatic test system based on GPIB Interface, Foreign electronic measurement technology, No.2:31-34
[3] Ji Fei (2012) Microwave Power Automatic Test System, Radar Science and Technology, Vol.10, No.5:549-552
[4] Li Dongfang. (2011) Research and Implementation of automatic test technology for digital array radar transceiver components, Fire control radar technology, Vol.40, No.2:66-71.