Design and Implementation of Small Satellite Flexible Test Bed

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***Abstract*—This paper analyzes the character and performance of the synthesized test bed on ground of small satellites. By studying several small satellite systems, the hardware and software architectures of flexible test bed are presented. The communication request/reply relations as well as other communication parameter's dynamic configuration, TM data format's dynamic description, TM signal's automatic analysis and presents, on-board internal as well as communication monitor between satellite and ground on satellite host computer and each kind of lower computer functional simulation and so on, provides an general test simulated platform for each constituent's development on-board, has built a closed loop simulation testing environment for the entire satellite jointing debugging. Dynamic configuring each kind of parameter is the concrete manifestation of the test platform flexible thought, the flexible test bed's realization establishes an general test simulated platform for the smallsat development, has made up the traditional special-purpose test system's insufficiency. The design and corresponding implementation are proven very effectively on the development of three small satellite systems.**

***Index Terms*—test bed, parameters configuration, telemetry, signal resolution**

I. INTRODUCTION

Any new product's development is not at one stroke, the design proposal needs unceasingly revision and consummation, before placing in operation, for guaranteeing product safe and reliable, must undergo the strict test. The analogue, simulation and modeling as three important technological means of the computer system performance appraisal that their suitable situation is different [1]. In the smallsat development, besides strict and thorough design, the simulation test is also one kind of important technological means [2,3,4,5].

In the smallsat's developing procedure, the overall project design iterates unceasingly, the data format of TM-telemetry/ TC-telecontrol, each subsystem's communication protocol on-board, each kind of lower computer input and output data and so on are also revising unceasingly, but these subsystem's development is undertaken by the different department, some departments are also in the different region, therefore any small modification about system design inevitably brings about re-coordination about each department, moreover, the various departments duty's relative independence and the region are scattered, cause these related departments not to be advantageous for partial joint debugging, like this, after various departments single computer check and accept, the overall joint debugging duty enlarges, moreover the part rework is inevitably, thus affects the development cycle of the entire satellite, increases the development cost. The simulation test of the traditional small satellites usually is that one kind of concrete model have a set of simulation test system, iterates unceasingly along with the entire satellite system design and revises repeatedly, the corresponding simulation test system also needs unceasingly revising and maintenance, once this model launches successfully, this model's simulation test system has also completed its own mission, and put it aside. Based on the above reason, proposed the demand which establishes the flexibility test bed of the small satellite [6], its goal is establishes one simulation test platform which have certain versatility, prolong the service life of simulation test system, strengthens the partial joint debugging ability, lightens the overall jointing debugging burden, reduces the simulation test period, provides the technical support in the simulation test aspect for each development department of the small satellite.

The smallsat flexible test bed is one kind of platform which simulates each kind of TM/TC data, each kind of lower computer input and output data, the ground synthesized test bed to each satellite subsystem as well as the entire satellite, through simulates each kind of TM/TC signal, each kind of lower computer input and output data in this platform, carries on the integral test [7,8] to the entire satellite's computer system, gains simulation test data, and carries on the analysis and appraisal, achieves eliminating the hidden danger, enhances the system reliable.

The 2nd of this paper gave the smallsat test overview, the 3nd gave the flexible test bed's software and hardware structure, the 4rd take main engine system of some model satellite service as a background, formulated the flexible test bed design's basic philosophy and method, the 4th declare briefly flexible test bed's practical application situation and performance.

II. SMALLSAT TEST OVERVIEW

A. Smallsat testing demand

Presently, the smallsat design tends to use standardized, modular, serialized concept, formed the satellite observation, posture/orbit control, communication, management/signal processing, energy and so on many modules. Their relative independence, becoming subsystem, and through field bus connection, constitutes the network on the star, forms entire star synthesis

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automated system of the operational guidance, the autonomous controlling and the information processing. Smallsat's composition principle and development method set the following request to the satellite testing:

1) The smallsat system is one whole that forms by many constituent unions which has the specific function. They are interact, interdependent, mutual influence and coexist, inalienable with each other. Various part of characteristics as well as coordinated mutually and divert, have formed the whole characteristic. Therefore, the test not only needs to inspect the function, the performance of each constituent, must inspect the mutual connection and restrains between various parts whether to satisfy requests.

2) The smallsat system's testing is a gradually refining process, is one amend process unceasingly. In this process, needs to adjust, changes original good parameter and function. Therefore, the test should establish the testing platform of the ‘flexibility’ interface based on analysis, induction and summary. Satisfies the testing command to the request for increasing, deletion and modification in the test procedure, satisfies the request for parameter change and revision in the test procedure on the star to the order frame and the telemetering downward data frame.

3) The smallsat system's testing is the process which is from ‘part’ to ‘whole’, is the process that both coordinates and diverts mutually. Therefore, the test must have the ‘simulation’ function, coordinates through software and hardware to realize simulation function on the star subsystem. At the same time, can interconnect with the subsystem equipment, realize pays equipment's pre-approval; On the other hand, when the independent subsystem in the satellite system cannot normal work (or equipment is not equipped completely fully), when have the influence to the systematic testing, can substitute this subsystem, constructing closed loop run-time system, completes producing and transmitting the star network command, inspecting the running time and matching the logical relation, enables satellite system's development to be in parallel with carrying on.

4) Smallsat's test not only need be suit for the combined test in the laboratory situation, but also must satisfy the stable test under other experimental environment. Therefore, the test must have ‘the configuration’ function, can carry on ‘detach’ and ‘assembly’ to the test module, carries on working by the single computer way or networking way, satisfies the different application situation.

5) smallsat's test is the process which debugs unceasingly, is process which consummates gradually. Therefore, the test must have the function of the ‘data storage’ and ‘historical playbacking’, not only need be able to realize the complete record of the test data, moreover must be able to realize the repeated reproduction of the history test data. It is advantageous with the debugging inspection in the test procedure, is advantageous with the generalized analysis in the test result.

In brief, the smallsat test must be able to be adapt to request the researching smallsat signal and parameter change and so on; Must be able to inspect and discover various parts' mistake on the star in the subsystem; When the subsystem presents breakdown, can remove the mutual diversion of each constituent, guaranteed that the test continues.

B. Synthetic Test Environment Building Method

The commonly used building testing environment's method has three kinds: Software prototype method, hardware prototype method and mixing method.

1) Software prototype method: Constructs the testing environment completely using the software method. The construction testing environment's language has many kinds, for example: C, VHDL, Matlab and so on. The software prototype's method characteristic is the environment construction and revision is quite flexible. But constructing and the system same prototype using the software needs to spend the very long time.

2) Hardware prototype method: Establishes a set the hardware prototype which equates completely with the system to carry on the test to the software. Hardware prototype construction testing environment is equivalent with system function completely, therefore tests is quite real; But the hardware prototype's simulation is not very convenient, sometimes cannot simulate system's behavior in true environment, for example, GPS correspondence and needs to be able to output the orbital data in the satellite flight process, the static state is unable to obtain the orbital data, therefore it is very difficult in the ground testing procedure to use the hardware prototype to simulate GPS correspondence and the flight behavior.

3) The mixing prototype method: Using method of the combination of the software and hardware to simulate system behavior. Using the multi-purpose gathering card to simulate data interface, using the software to the single plane system behavior to model This methods design is simple, the revision is flexible, may add the function which needs to the system one by one, may also delete the function which do not need. The mix prototype method is the current widespread use construction method.

C. Ground synthetic test duty and method based on housekeeping

Ground test's primary mission is examining each part's compatibility in the system, part's performance under system active status, external interface characteristic as well as system's function and performance under each running mode.

According to test loop's nature, the ground test method may divide into the open test and the close tests two kinds. The opening test is that the test system transmits static pumping signal and each kind of instruction to the measured system, and accepts the measured parameter and each condition through the checking point and the telemeter point, and carry on the contrast between the actual value and the setting value. The close test is the test system transmits initial condition, the real-time dynamic pumping signal and instruction to the measured system, then gathering the measured system's movement parameter and the status messages, and revise the corresponding pumping signal by the test system,

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simultaneously record to supply the analysis to adjust reference.

The test system not only is able to take the nominal value to the important performance parameter, but also consider the bound. At the same time, carries on the test item under the environment, its main part must be able to be suitable for the entire star test of the general equipment department factory and decoy launching.

III. SMALLSAT SYSTEM'S ARCHITECTURE

Ground synthetic test system based on star service system take satellite service computer as a core[7,8], provides the periphery single computer's simulation and interface for the satellite-bone computer, so that each satellite subsystem's debugging and tests, therefore main computer of the satellite service's architecture has decided the constitution of the ground test system. The Smallsat system is composed by the satellite service main engine, the attitude control, the correspondence, the payload as well as the space environment (i.e. structure, energy and thermal) and so on several major parts.

Its characteristic takes housekeeping main computer as central management pattern primarily, the housekeeping main computer monitors the satellite each subsystem's condition through gathering essential data, and does with request to each subsystem's duty, thus can complete the satellite mission independently.

The housekeeping main computer mainly completes the following function.

① Provides the unified clock signal of the satellite, by ground, GPS timing

② Controls remotely the indirect instruction, receives, analyzes and carry out the input data

③ User data's receive, saves and transmits

④ Data analysis and processing on satellite, produce independent management control signal

⑤ Telemetric data's pack, transmits

⑥ Attitude control subsystem's management, posture capture after satellite rocket separation, injection normal control as well as fault mode movement.

⑦ The correspondence subsystem's management, including spread spectrum communication's data receiving and dispatching, narrowband correspondence's data receiving and dispatching as well as the breakdown monitor and processes

⑧ Thermal management

⑨ Energy control management

⑩ Other star service management

The housekeeping main computer is established for completing each subsystem's independent management on satellite, because the smallsat volume is small, the power loss is low, the function is relatively unitary, generally uses dual system's central management, dual system also moves, cooperation based on division of labor, mutual supervision completes the management task together.

The connection relations of the housekeeping main computer with other subsystem are shown in Figure 1.

In order to realize the closed loop test of the satellite system, avoids other subsystem's influence, needs a set of simulation analogous system to come equivalent other subsystem's function. Ground synthetic test system [10] is designed for this reason.

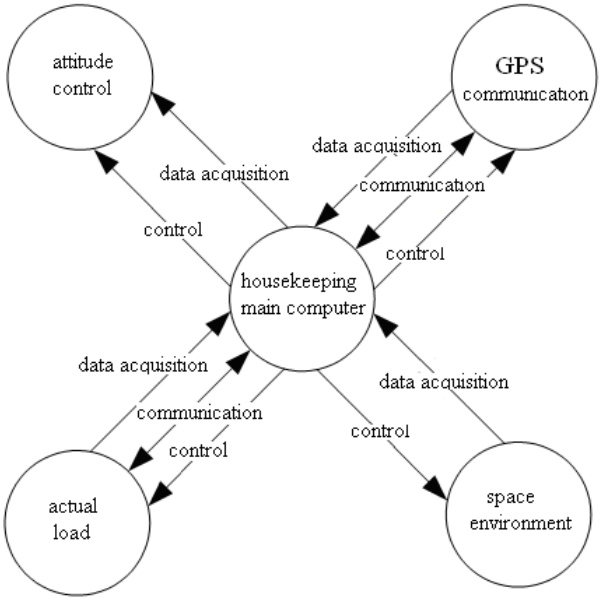

Figure 1. The incidence relation between the housekeeping main computer and other subsystem

At present the analog simulation test system's architecture divides into two kinds approximately[11,12], the single computer platform and the distributional platform.

In the single computer platform, all inputs and output as well as the data are on the identical computer, therefore does not have the correspondence question of the interactive duty. This kind of systematic design is relatively simple, generally uses the analog simulation test system, like ADS3000, ATEC6 and so on, and is based on VXI (Versa module europa bus extensions for Instrumentation) main line's single computer platform analog simulation test system.

In the real-time simulation domain, system's function is complex, not only has the massive orders and the data to process, but also needs to produce the measured system's input signal, collection, the measured system's movement result according to the test data of the test system, demonstrates each kind of interacted system's condition. As a result of the single computer platform CPU handling ability's limit, must complete the above function complex real time system is obviously not realistic, next, uses single computer platform affects system's extendibility. Therefore must use the distributional analog simulation test system, which is much computer coordination processing duty. The distributional structure, may increase the new task processing computer according to need on the existing system, realizes the maximum limit match specific duty.

The flexible test bed is consisted of the subsystem on-board and the ground subsystem two parts. The flexibility tests bed's hardware architecture is shown in figure 2, the systematic constitution not only limits the equipment which shows in the figure, according to the simulation's

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demand, may expand one or a bunch of terminal equipment and VXI/PXI (VXI: Versa module europa bus extensions for Instrumentation, PXI: PCI extensions for Instrumentation) equipment.

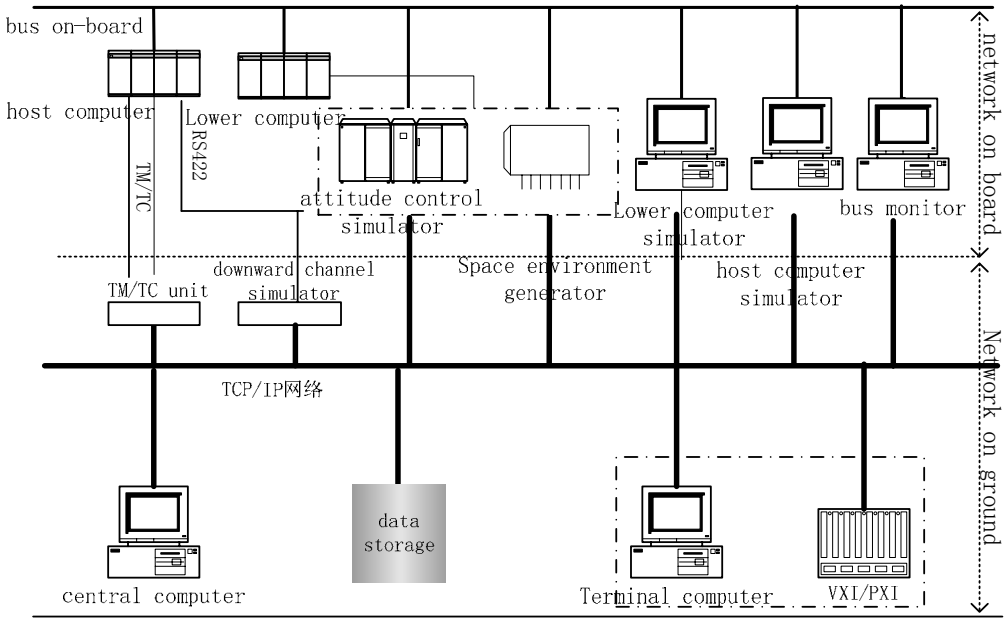

Figure 2. Flexible test bed architecture

The equipment on-board uses the standard CAN (Controller Aera Network) main line or other bus interfacing, is a double return route communication network, the equipment on the satellite and the above-ground equipment as well as between the above-ground equipment connects through local network.

Each simulator uses the same structure, as shown in Figure 3, uses the mix prototyping method to carry on design, constructs the behavioral model of various lower computer on the satellite to simulate each lower computer function, in which lower computer behavioral model may be the pure software model, may also be half working model, may also be the working model. Uses multi-purpose collect and control system card to realize the behavioral model and the housekeeping main computer's interface, achieves the housekeeping main computer and each simulator's closed loop testing environment.

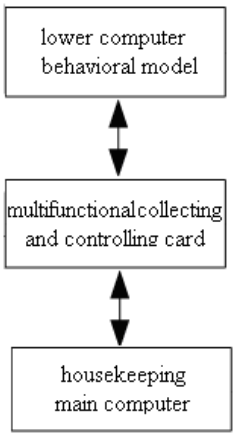

Figure 3. Lower computer simulator structure on satellite

IV. FLEXIBLE TEST BED SYSTEM DESIGN

The software architecture of the flexible test bed may divide into three-level. The lowest level is hardware device driver; The intermediate level is the test module library, carries out the concrete test, unified management by high-level program; High-level is system's management, mainly includes: Test configuration, test dispatching, test control, network service, data storage, data issue, system maintenance and so on functions. Software level diagram is shown in figure 4.

The ground synthetic test system may divide into the online test and the off-line tests according to its movement's nature. The online test includes the input and output management, the data acquisition, the simulation model, the test object and content definition, the telemetric data gain and monitoring, the remote control command roughly producing and processing, the special purpose equipment control and so on. The off-line test mainly completes analyzing to deal with to the data, including analysis result output, empirical datum playbacking and so on.

Because the test is the process of a iteration, revising unceasingly, needs to make the parameter adjustment to system, including communication protocol, the request/reply relations form among lower computer, host computer and the lower computer and so on; The smallsat TM data's organization way, like the data frame structure, the TM signal in the data frame the position, the signal category, the signal physical meaning, the signal presents and so on changes; Therefore the testing software must adapt the domain characteristic, causes the communication protocol, the request/reply relations form, the interface layout, the TM data organization and so on to be resetting, reduces union debugging cycle of the satellite service system, reduces expense, enhances reliability.

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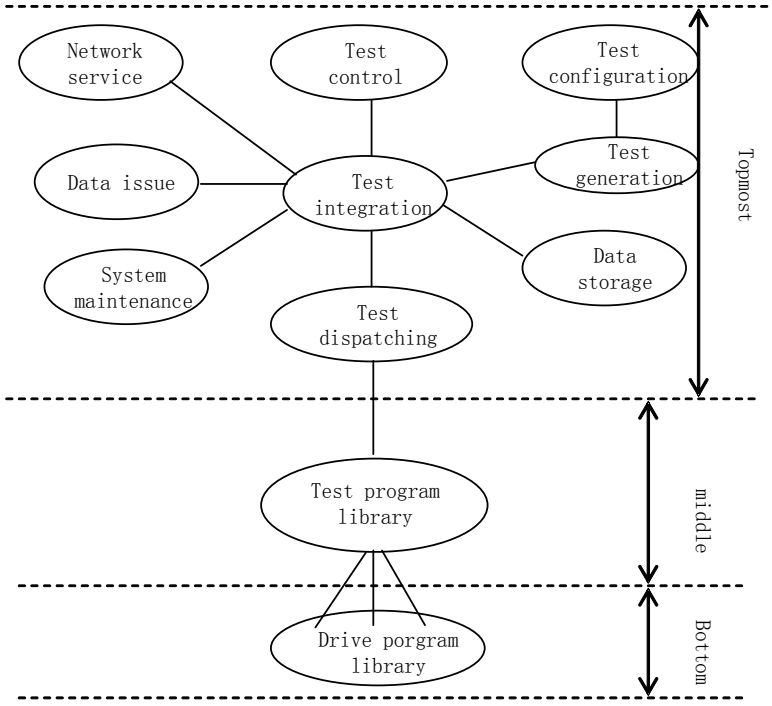

Figure 4. flexible test bed software level diagram

A. *Ground testing system function and design principle*

The smallsat housekeeping tests platform is the important component of the satellite development work, its major function is as follows:

1) The compatibility and stability of various parts combined operating in tracking and examining system;

2) Develops, debugs, and examines system's application software;

3) Carries on “the seal” to the housekeeping system, realizes the whole payment of the subsystem level, reduces the test burden in the entire star, speeds up development schedule of the entire star;

4) As the trouble shooting and the analysis tool;

5) Constitutes the entire star test system jointly with other subsystem test facility;

The ground synthetic test system's design principle includes hardware and software two parts.

1) hardware part design principle:

Failure isolation: The test system hardware fault cannot interfere with satellite system's work, does not bring the disastrous breakdown for the satellite system.

Resource sharing: The hardware design uses the modular structure, coordinates with the testing software, and realizes the hardware source flexible disposition.

Connects simply: Integrated design system's connection relations from system's reliability, connection's accuracy and test cost and so on aspects, in satisfy function, performance, under the stable premise to reduce test system's complexity as far as possible (e.g.: Partial hardware functional software).

2) software part design principle:

Stability: The systems operation is stable, the test result is real and credible.

Security: Has the correct handling ability to the wrong input; The operation jurisdiction is strict, operation history records.

Integrity: The test data is complete, does lose data; the test function is comprehensive, the test coverage rate is high; The test inquiry is flexible, the test expresses is rich;

Flexibility: According to the software agreement on the satellite, provides the user to carry on the signal disposition, the parameter disposition, the interface disposition, configurations and so on functions.

Extension: System's design should satisfy the test request which the satellite grows unceasingly, leaves interface for test system's expansion.

B. *Flexible test on-board bed subsystem functional design*

Subsystem software logical organization on-board is shown in figure 5. In the different model small satellite system, the correspondence request/reply's relations, the correspondence frame's form and the physical meaning between each subsystem on the satellite are different. Onboard payload subsystem of the flexibility tests bed may be possible to act according to the request of the concrete model, dynamic defines correspondence request/reply relations between the main engine and the lower computer, between the lower computer and the lower computer, may according to demand to redefine the data form which is transmitted in the course of communications, simultaneously supports many kinds of order transmission pattern between host computer and each kind of lower computer. According to the overall request may simulate communication process of smallsat's each subsystem, and provides the corresponding simulation input and output data, thus achieves simulation to the smallsat's each subsystem, provides the powerful support for each development department's partial jointing

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debug, causes each subsystem's development to be the parallel development, reduced the coordinated time between each subsystem, and is helpful to find problem as soon as possible and solves the problem.

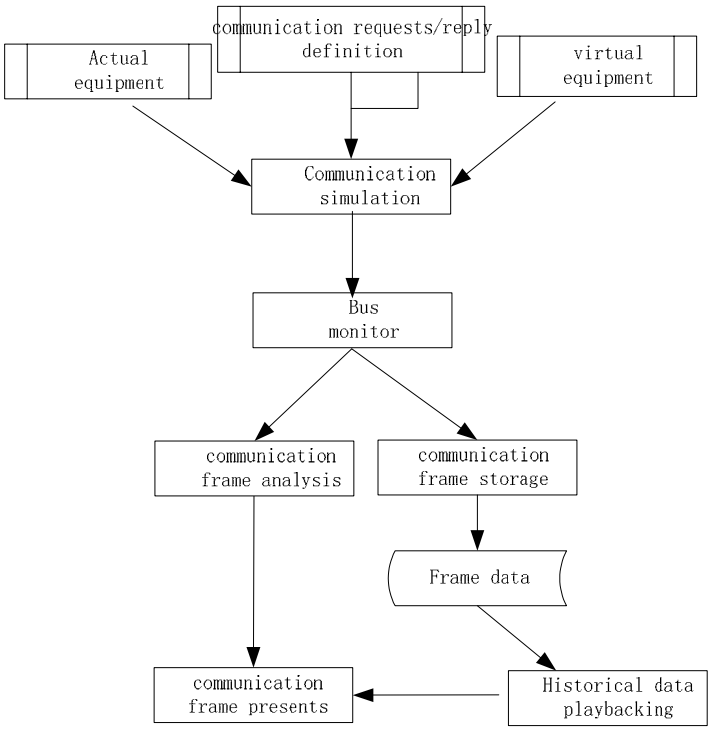

Figure 5. subsystem software logical organization on-board

The bus monitor is the black box that records complete communication process on-board system. The bus monitor main completes: Monitor communication information flow between satellite and ground, each subsystem, record bus's each kind of information; Analyze the data message which monitors based on definition of the related communication protocol, records the related error message and the related diary; Real-time recording system communication complete process; Provides information playbacking function, may playback the historic record of the random time; Can filter to bus's data message, monitor specific information flow selectively, like only monitors communication data flow between the host computer and the lower computer, or only monitors communication data flow between satellite and ground and so on.

C. Flexible test bed ground subsystem functional design

Smallsat's ground control center is responsible for receiving the TM data which the smallsat transmits, and transmits the corresponding TC order to smallsat according to needs. receives the TM data real-time which smallsat transmits, and analyzes and memorizes real-time these TM data, presents promptly them in the control center terminal, uses for the ground analytical control, simultaneously transmits the TC order according to the concrete need to the satellite at any time, realizes regulation to satellite.

The ground subsystem software is composed of the control center software, the terminal software, the data-base management software and so on, completes analytic processes and presents to the TM data, as well as remote control to the satellite, realizes the ground-to-satellite loop operation. And control center main software logical organization is shown in figure 6.

D. The test bed main part realization

Communication request/reply relations configuration on-board among various equipment, TM data's dynamic analysis, data flow information's monitor on bus is three important links that realizes the flexible test bed, and the concrete realized structure of communication request/reply relations configuration and the TM data dynamic analysis two parts is shown in figure 7, figure 7 (A) is the structural framing figure that realizes communication request/reply dynamic configuration between the smallsat lower computer and the lower computer, the lower computer and the satellite service host computer, and including may configure data frame form that network on-board under different bus communication protocol as well as define each kind of initialization parameter of the satellite subsystem. Layout data in logic is independent in subsystem's realization, the change of configuration does not affect subsystem's structure. Figure 7(B) is the essential part of the ground subsystem, has defined one kind of semi-structured description language, through description and definition to the TM data's signal type, attribute, characteristic and so on, as well as carry on description to each kind of signal (simulation, digit, temperature and so on) layout in user interface's as well as presentation in the contact surface (digit, graph, switch, condition and so on), has formed the ground subsystem's dynamic behavior static description. The ground subsystem's signal analysis and the interface explanation part rely on grammar and the semantics of the

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description language, they complete analysis and present of the concrete signal by the signal resolver, but descriptor in logic is independent in resolver, revision of descriptor does not need revise the resolver code to be possible to reflect this kind of change promptly.

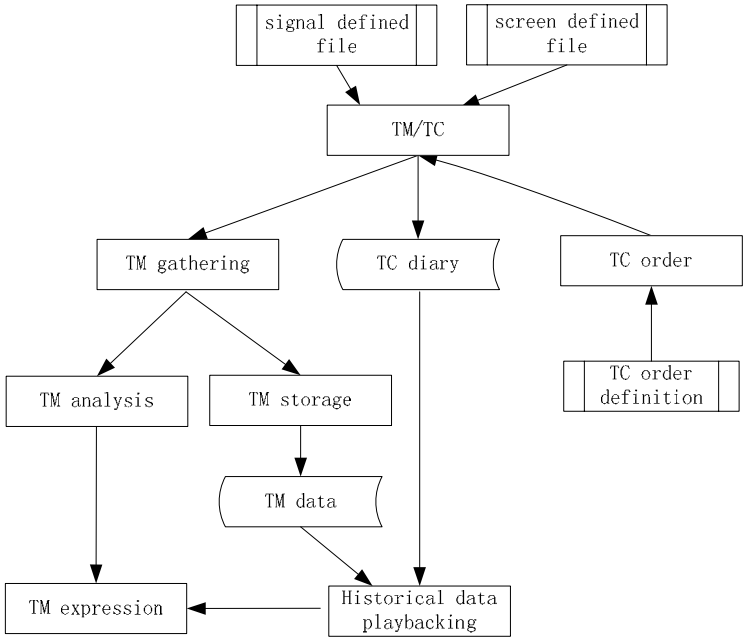

Figure 6. Control center software logical organization

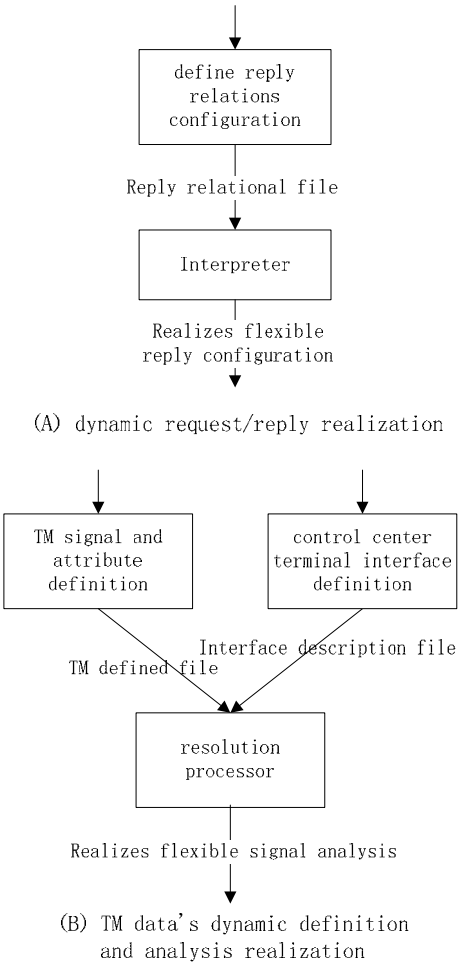

Figure 7. Flexible test bed part realizing structure drawing

V. CONCLUSION

This paper has full studied the on-board network communication protocol as well as the TM data frame structure of several type small satellite, proposed and realized the smallsat flexible test bed. The communication request/reply relations as well as other communication parameter's dynamic configuration, TM data format's dynamic description, TM signal's automatic analysis and presents, on-board internal as well as communication monitor between satellite and ground on satellite host computer and each kind of lower computer functional simulation and so on, provides an general test simulated platform for each constituent's development on-board, has built a closed loop simulation testing environment for the entire satellite jointing debugging. Dynamic configuring each kind of parameter is the concrete manifestation of the test platform flexible thought, the flexible test bed's realization establishes an general test simulated platform for the smallsat development, has made up the traditional special-purpose test system's insufficiency. For instance payload equipment development department, after the single machine design test completes, in the situation of no satellite host computer, the related partial joint debugging in the past only can postpone it down after the single machine acceptance, is responsible for joint debugging by the overall, now has the flexible test bed, may provides the satellite host computer's analog simulation function which using the flexible test bed, carries on joint debugging the payload and the satellite host computer ahead of time, thus may discover flaw and insufficiency early in the design, raise the working efficiency, reduces the development cycle.

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At present in the developing smallsat system, the flexible test platform provides the technical support of the test aspect for each department's development. In brief, the flexible test bed has made the satisfactory progress in the practical application, has achieved the project objective.

The flexibility configurable thought has certain reference significance to other similar military systems and model research, as the next step work, this system needs the deep research to the smallsat domain, establishes the software architecture of this domain gradually (DSSA:Domain-Specific Software Architecture), further raises the research and development efficiency.

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