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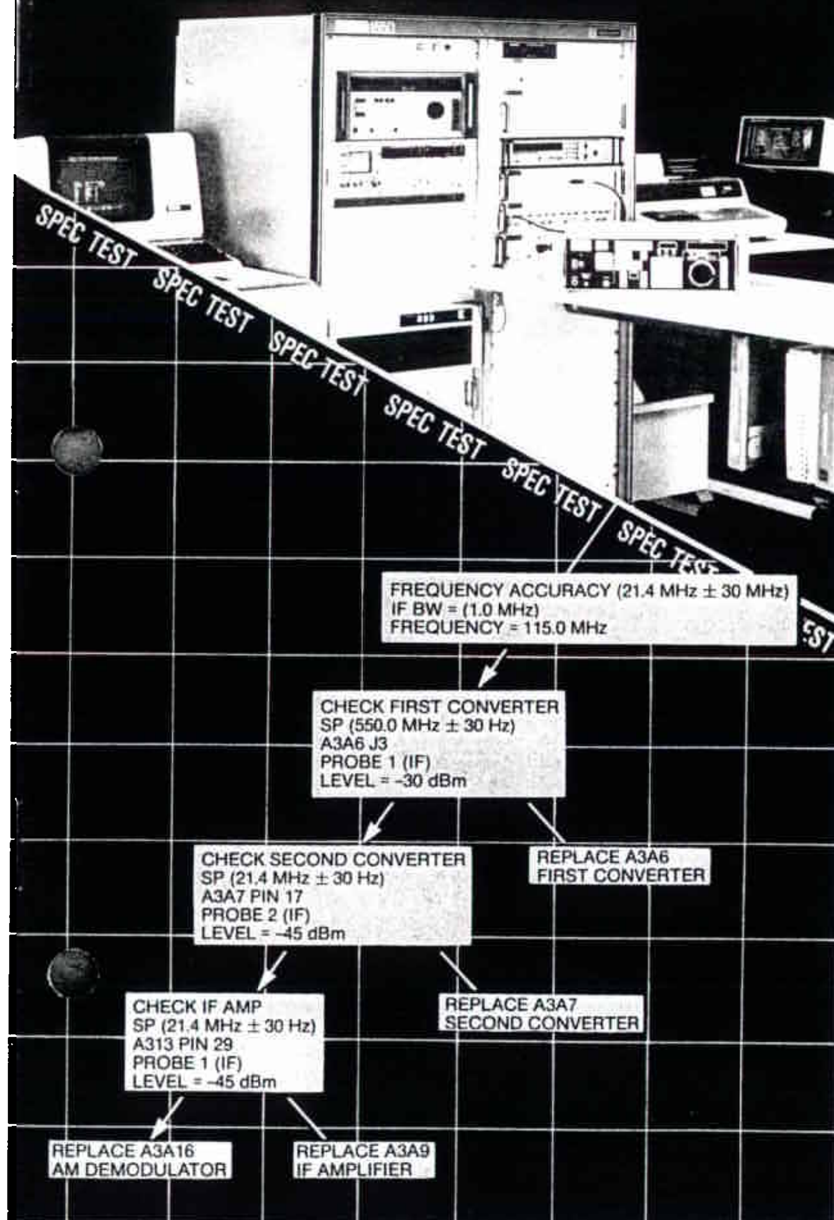
Design Considerations for Automated RF Test Equipment



Radio frequency (rf) equipment repair facilities face a number of challenges in developing and applying effective test strategies. Modern communications systems are not designed around a single technology. Equipment manufacturers offer varying implementations based on an array of technologies. Naturally, test requirements for this equipment are becoming more demanding.

Maintenance organizations must possess the right resources necessary to test and repair these complex systems. Defining the optimum combination of manpower and test equipment for such a facility requires proper forethought.

This article explores communications systems test and repair by establishing general design considerations for an rf automatic test equipment (ATE) system, outlining test requirements for one class of rf equipment, and presenting a specific implementation.

Repair of RF Equipment

The repair process for an rf system that is assumed to be defective involves the following activities:

a. System-level performance verification (GO/NO GO test).

b. Fault diagnosis to subassembly or module level.

c. Replacement or rework of failed subassembly/module.

d. System-level performance verification (GO/NO GO test).

This type of process is characteristic of intermediate-level maintenance functions. Depot repair extends the process to include performance test of subassemblies or modules and diagnostic capability to a single component or group of components.

Surveillance receivers (a particular class of communications receiver) scan or monitor predetermined frequency bands to acquire and process transmitted information. These intelligent receivers are software-guided through external controllers, and contain microprocessors to direct internal-decision processes. Extensive digital, analog, and rf signal-processing circuitry is found in their design.

As a result, a repair facility needs a wide range of stimulus and measurement equipment. Furthermore, surveillance receivers are designed and constructed in accordance with the individual equipment manufacturer's methods. Repair shops deal with receivers manufactured by many companies. As a result, the degree of testability varies from company to company. Additionally, repair shops, in particular, military facilities, face shortages of skilled manpower due to frequent personnel turnover.

Alternatives

Manual test and repair of receivers is accomplished with standard bench test instrumentation, a host of coaxial cabling, terminations, clip leads, and OEM-supplied troubleshooting procedures. A skilled test technician follows vendor-prescribed test procedures to develop performance test and diagnostic data. All activities, including setup of a receiver under test and test instrumentation and the collection and interpretation of data is dependent upon the technician. Human error is introduced through misinterpretation, improper setup, or shortcutting prescribed procedures. In general, rf-test approaches tend to be costly. The process is labor-intensive, time-consuming and dependent upon knowledgeable test personnel.

Automatic test equipment, when properly implemented, substantially improves productivity in a repair facility. Increased speed and throughput, accurate and repeatable test results, and a reduction in test personnel skill-level requirements are general benefits of automation.

ATE systems are comprised of stimulus/measurement functions, a unit under test (UUT) interface, an operator interface, a system controller, a software test executive, an operating system, and application programs. Figure 1 illustrates a basic configuration for automatic testing of an rf system. A test operator activates an application program to direct and control the test process. Structured algorithms guide the system controller to route stimulus and measurement functions to and from a unit under test via the UUT interface. The system controller records and analyzes test results. Test results may include simple performance test data or detailed diagnostic information.

RF ATE Software Considerations

RF systems may be tested on the basis of two separate criteria. A UUT can be described by either:

a. class-dependent characteristics; or

b. manufacturer-dependent characteristics.

Class-dependent characteristics represent a group of operating parameters or specifications that apply to an rf system. All surveillance receivers are characterized by a set of operating parameters. These include frequency range, noise figure, IF bandwidths, third-order intercept, sensitivity, etc. Manufacturer-dependent characteristics are derived from the specific design of an rf system, and include extraordinary operating features. Manufacturers of surveillance receivers often offer user-specified modules as options. These options could be IEEE-488 control, special demodu-

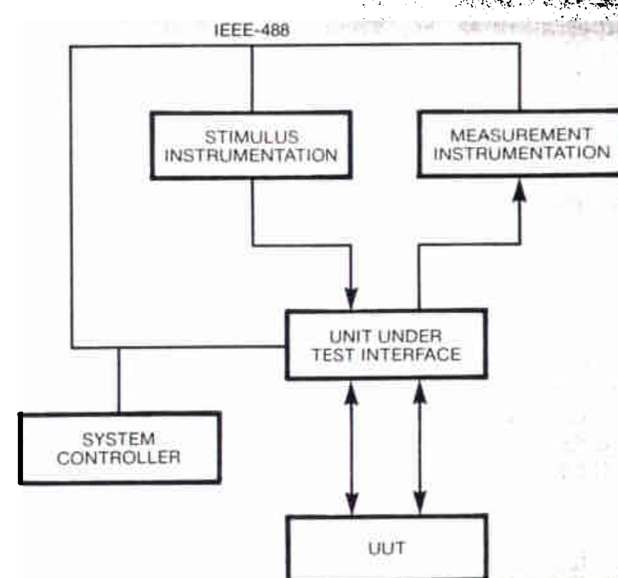


Figure 1. Basic ATE setup.

lators, software control or signal-recognition modules, all of which affect the individual configuration of the testable.

These characteristics drive the most important objective of rf ATE system design: minimize application software development. Applications software development (especially in military environments) is a high-dollar cost item. Software development can nearly quintuple initial ATE hardware acquisition costs. If the environment for producing application test programs is not oriented toward maximizing the productivity of the test programmer, much time and money is wasted during the development process. Advanced software techniques are required to effectively reduce test-program development costs.

The Operating System

The first consideration in selecting an ATE software development environment is the operating system. The operating system provides user access to system peripherals and instrumentation. Ideally, it should allow several users to run several programs at once. Thus, an operating system with "multiuser, multitasking" capabilities is desirable.

Hardware is changing at a faster rate than in years gone by. Present day microprocessors may be rendered obsolete in as little as five years. ATE vendors make a significant investment in developing the software environment that controls ATE functions. This software should be able to evolve as time goes on, and not be subject to obsolescence because of the system hardware on which it was developed. Thus, portability of software is another factor for the ATE vendor to consider when selecting an operating system.

The RF ATE Software Environment

The rf ATE software environment should present system capabilities to the operator in a straightforward manner. This enables the operator to concentrate on testing and repairing the UUT without distractions that often come with complex systems software. The ATE software environment should provide the following capabilities to allow for efficient creation and utilization of rf test programs:

a. high-level test language

b. screen-oriented test program editor

c. test executive

These capabilities must be effective as well as being easy to use.

High-level Test Language

The test language provides the commands necessary to automate the test process. The language, as a minimum, must provide the test programmer with the capability to:

a. program-test instrumentation

b. determine pass/fail status

c. perform conditional branching

d. execute iterative loops

e. control terminal I/O

There are many other desirable features that a test language should have; however, first and foremost is that it be *usable.* Too often test languages require one to have an extensive software background in order to generate effective test programs.

Providing the ability to call external test functions is a feature worthy of note. Function calling would allow the test programmer to utilize previously written test functions resident within an external library. In the case of receiver testing, providing a library of general purpose receiver-specification tests greatly simplifies the test programmers task. Each specification test depends on variables such as frequency range, signal level, expected output level, etc. The variables would be defined prior to calling the test. These specification tests would be general-purpose tests, allowing them to be used on almost any receiver.

The use of external test libraries that are linkable to a test program is a valuable asset to an rf ATE system. In particular, a receiver specification test library would greatly reduce the amount of time required to generate diagnostic receiver test programs. External test libraries could (and probably should) be developed by the ATE vendor. Flexibility to allow the end user to add or modify tests within the library must be provided.

General purpose external test libraries provide access to already-written and debugged test functions. The availability of linkable generic test routines can greatly reduce test-program development costs, and is worth considering when selecting a test language for use.

Screen-oriented Test Program Editor

The screen-oriented editor is an editor that displays modifications to a program as they are made. Editors of this type are often referred to as "visual" editors. A screen-oriented editor can drastically reduce test-program development time when compared to a line-oriented editor. Most outdated editors are line oriented, and do not display changes made to a program as they occur.

In addition to providing a screen-oriented editor, it is desirable in an ATE software environment to have the editor perform an interactive check of statement syntax. Grammatical or syntactical errors should be reported as they are detected, with a concise error message stating the problem. This feature is particularly desirable when dealing with the novice user. Time spent shuffling between the editor and compiler/executive due to incorrect test program statements can be eliminated.

The screen-oriented test program editor should also have string-search and page-forward/backward capabilities. This allows for efficient location of statements within a test program. The capability to pick up and drop blocks of code is an added plus. Blocks of code that are similar within a test program can then be entered faster and with fewer errors.

The test-program editor is the most heavily used software utility during test-program development. Because of this, editor commands should require a minimum of keystrokes. Labeled command keys, preferably utilizing a data-entry keypad (most terminals have them), simplify use of the editor and make it easier to learn. Keys should be clearly marked and easy to understand.

Test Executive

Once a test program is written, a test executive is used to execute the program. Measurements are taken, pass/fail status is determined, and failures are diagnosed. The test executive must offer these capabilities. Simply executing the program, however, is not enough. A variety of execution modes must be offered to provide adequate flexibility in controlling test program execution.

In order to follow the execution of a test program, particularly during the debug phase, a method of "single stepping" through the program is necessary. This allows the test programmer to accurately follow what is happening in the test program. Verbose execution of each test program statement should also be a selectable option. It provides for a visual display of each test program command as it is executed. Hardware status can then be interrogated at each step to verify that the test program is doing what it should. High-level programming languages provide these debugging features.

The test executive normally will run a program in a "halt on failure" mode. Upon occurrence of the first failure, the program halts and displays a message indicating the occurrence of the failure. Flexibility within the test executive must be available to allow the option of ignoring failures, effectively allowing complete end-to-end execution of the test program, regardless of pass/fail status.

Interactive command execution is often neglected in ATE system design. This is primarily useful in communicating with test instrumentation (generating and switching signals, taking measurements), but also can be used to perform interactive calculations on readings. Block or codes can be tested in this fashion before being entered into the test program. Test language commands are typed in manually, and each command is executed as it is entered. This provides immediate command feedback in an interactive fashion. Interactive command execution provides an efficient way to learn a new test language, and to become familiar with new hardware.

An Implementation

Watkins-Johnson Company has developed a line of automatic rf/microwave test systems to address the needs of communication equipment production test and repair facilities. The WJ-1550 RF/Microwave Test System offers turn-key performance test and diagnostic capability for rf systems operating in the 5 kHz to 1.3 GHz region. The system is expandable to 18.0, 26.5, 40.0 and 60.0 GHz.

A compute-intensive test philosophy provides the capability to develop test programs that (1) verify performance of an rf system, and (2) diagnose faults to a single module or subassembly within a system. The WJ-1550 utilizes three primary tests in an application program. These tests are:

a. Specification Tests (SPEC)

b. Message Tests (MSG)

c. Signal Probe Tests (SP)

These tests are typically organized into an overall application program in accordance with the test-flow diagram shown in Figure 2. The nodes encompassed within the rectangular box depict the full end-to-end performance test of an rf system. Performance verification requires only MSG and SPEC tests. The MSG test directs the operator to connect the rf UUT to appropriate points on the UUT interface assemblies. Manually controlled receivers, for example, require that the operator be prompted via these MSG tests to reconfigure a UUT's tuning frequency, bandwidth, or detection mode. In this case, the SPEC test and the MSG tests are interleaved throughout the performance test program. For digitally controlled receivers, operator interaction is minimized. MSG tests are found at the front end of the performance test. Watkins-Johnson Company has developed a SPEC test library. These algorithms test the class-dependent operating parameters of an rf system. Table 1 lists a set of tests currently in the WJ-1550 specification test library. These tests are common to surveillance receivers and other communications equipment.

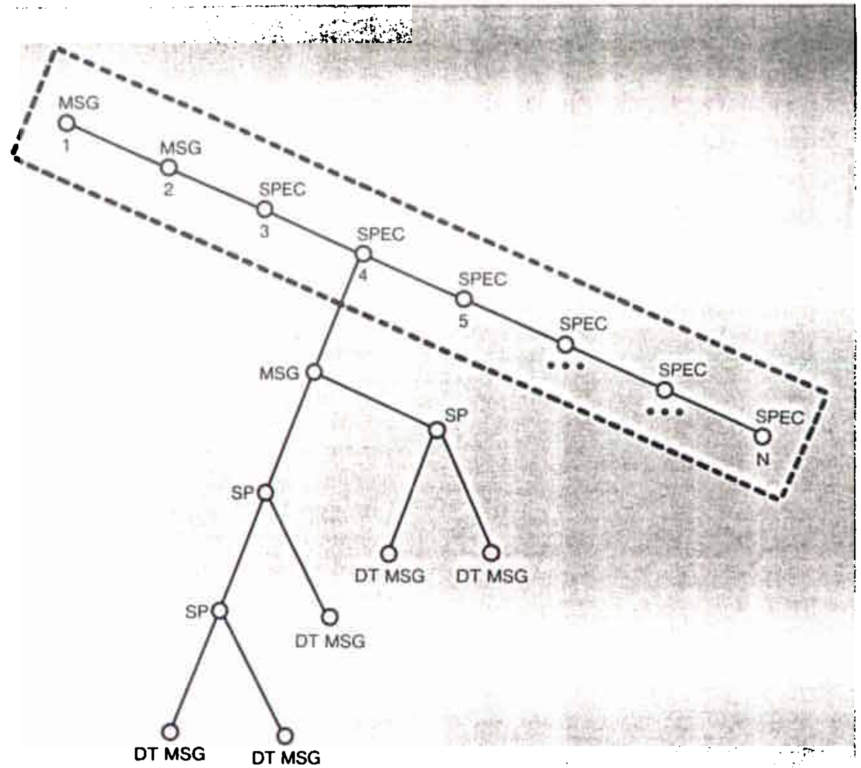


Figure 2. Test-flow diagram.

Diagnostic testing is initiated when a given specification parameter falls above or below its acceptable value. Once this occurs, a logical flow of MSG and SP tests are used to isolate a fault to a failed module. SP tests require that the operator "remove a testable's lid" and probe for power, frequency, time, voltage, and resistance values. Manual troubleshooting procedures are simply automated by linking these SP, MSG, and SPEC tests together using a diagnostic test editor.

The hardware composition of the WJ-1550 is modular. All stimulus and measurement functions are implemented with off-the-shelf IEEE-488 controlled instrumentation. The standard instrumentation set for receiver testing includes:

a. (2) Synthesized Signal Generators
   Sig Gen 1: 10 kHz to 1.3 GHz, 1-Hz resolution, +19 to -140 dBm
   Sig Gen 2: 80 kHz to 1040 MHz, 10-Hz resolution, 0.2 μv to 2 v emf in cw and fm, 0.2 μv to 1 v emf in am.

b. (1) Power Meter: 1 nW to 10 mW, 200 kHz to 18 GHz.

c. (1) Counter: 3 bands, 10 Hz to 18 GHz.

d. (1) Function Generator: 2 to 20 MHz, 20 mv to 20 v p-p sine, square, triangle.

e. (1) Digital Multimeter: 4½ digit resolution, dc, ac, rms, ohms.

f. (1) Oscilloscope: 80 MHz bandwidth, 500 v p-p ac to 1 kHz.

g. (1) Frequency Multiplier Assembly (optional): extends 0.5 to 1.125 GHz source to cover 1 to 18 GHz.

AGC Attack	Frequency Resolution
AGC Decay	Frequency Stability
AGC Range	Gain
AGC Threshold	IF Rejection
AM Sensitivity	Third-order Intermod
CW Sensitivity	Image Rejection
FM Sensitivity	LO Frequency Accuracy
ISB Sensitivity	LO Power
BFO Frequency Accuracy	Noise Figure
BFO Frequency Range	Sideband Rejection
Bandwidth	
Audio Distortion	

Table 1. Specification test library

Instruments are selected on a functional basis rather than by manufacturer.

The WJ-1550 system incorporates three UUT interfaces. They are the:

a. RF Control Interface (RCI)

b. RF Interface Assembly (RIA)

c. RF Processing Assembly (RPA)

The RCI provides power and control to an rf system under test. Control interfaces include RS-232, IEEE-488, MIL-STD-1553, or custom serial/parallel buses. The RIA is an IEEE-488 controlled-switching interface designed to route af and IF signals to and from a unit under test. Additionally, the RIA provides IF and af signal processing in the form of amplification, filtering, and line termination. The RPA is an IEEE-488 controlled-switching interface designed to route rf stimulus/measurement signals to and from a unit under test. RF signal processing capability is also provided in the form of attenuation, noise sources, signal combination, and line terminations.

The WJ-1550 system is operable from either a standard CRT/keyboard terminal or a touch-panel display. System operation is prompted through menu-directed selections on either display.

The test process is directed by a 10-MHz Motorola 68010-based processor housed in a DEC LSI 11 Q-bus compatible backplane. The system is configured with 1.25 megabytes of main memory, 65 mbytes of Winchester-based mass storage, and a 75-mbyte streamer tape subsystem for back up. Figure 3 illustrates the basic block diagram of the WJ-1550.

The WJ-1550 test software environment runs under control of the UNIX[1] operating system. UNIX provides both multiuser, multitasking capability, and portability of software across differing hardware environments. UNIX is growing in popularity, and has been introduced to computers ranging from the IBM PC to the Amdahl mainframe. It provides a software development environment that has been widely accepted by engineers responsible for software development. The multitude of utilities and variety of languages available under UNIX provide for a very efficient, yet flexible programming environment. These factors make the UNIX operating system desirable for use in developing and hosting rf ATE system software.

Creating an efficient test environment requires a great deal of software development. The WJ-1550 COLT-II (Conversational On-Line Translator) test environment is a second-generation set of ATE software tools. COLT-II provides the ATE user with the capability to create, edit, debug, and execute test programs with maximum efficiency. The complete list of WJ-1550 specification tests form the rf test library (RTL), and are available for use by the test programmer. These pre-written rf test routines can reduce diagnostic test development time. A screen-oriented editor simplifies diagnostic test generation. Interactive control of ATE hardware is provided as a programming utility. A test executive offers several different modes of program execution, providing flexibility in conducting unit test. The software capabilities offered by the WJ-1550 provide a test environment that substantially improves upon manual test procedures.

Additional software capabilities offered by the WJ-1550 include test-data management facilities within the rf test executive that organize test results into formatted data sheets and graphical plots. Test results can then be stored according to UUT serial number for use in failure-trend analysis.

1. UNIX is a trademark of Bell Laboratories.

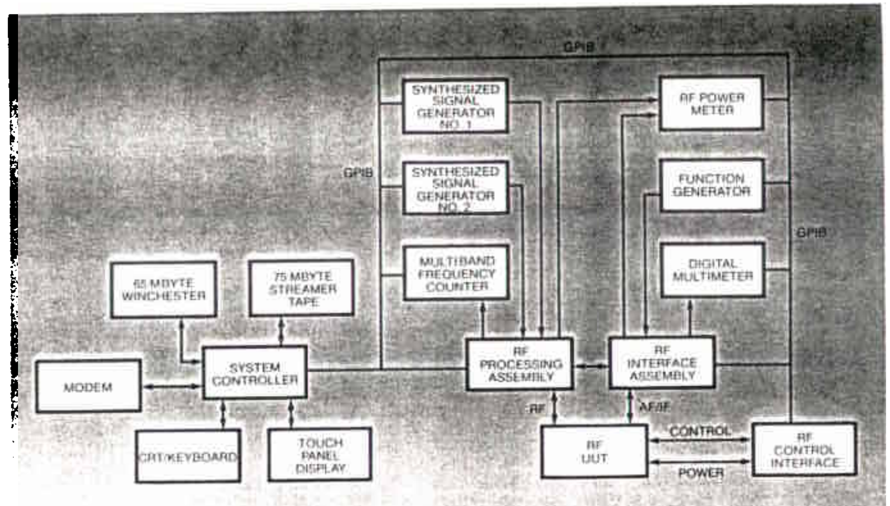


Figure 3. WJ-1550 basic block diagram.

A Receiver Test Requirement

The system concept is further illustrated by examining a WJ-1550 diagnostic test program set for a WJ-8618B vhf/uhf receiver. The WJ-8618B is a fully synthesized, digitally controlled receiver, designed to operate in the vhf/uhf frequency range. It receives am, fm, and pulse emissions over a frequency range of 20 to 500 MHz. The standard receiver is capable of manual operation, utilizing front-panel controls, or automatic operation utilizing a built-in microprocessor and 16-channel memory. Remote control is facilitated through either an optional IEEE-488 bus or RS-232 interface.

The operating circuitry of the receiver is contained within four main sections. They are the digital control, RF/IF, synthesizer, and power distribution sections. Interconnected via the main chassis by a network of control and signal lines to permit the various functions to perform as a complete system, each system is comprised of a number of circuit-card assemblies (CCAs). The receiver contains over 30 CCAs.

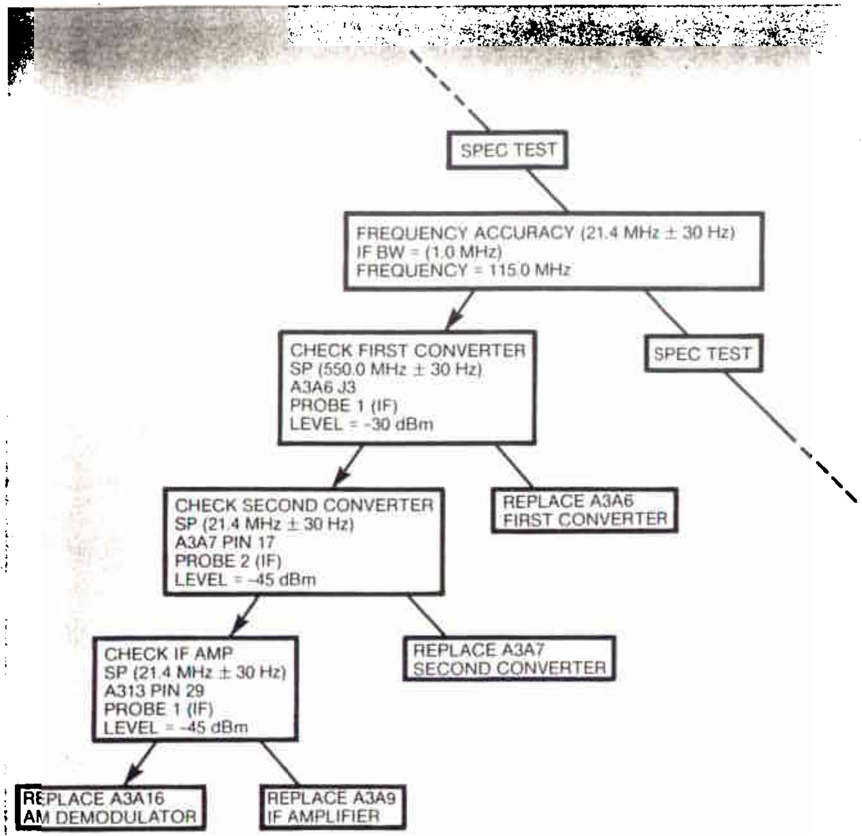


Figure 4. WJ-8618B test-flow diagram (frequency accuracy branch).

All external signal input/output ports, with the exception of the audio phone jack, are found on the WJ-8618 rear panel. Rear-panel ports include:

a. (2) rf antenna inputs (50 ohms)
b. (1) switched IF output (50 ohms, -30 dBm)
c. (1) wideband IF output (50 ohms, -30 dBm)
d. (1) fm monitor output (91 ohms)
e. (1) audio output (600 ohms)
f. (1) switched video output (91 ohms)
g. (1) display outputs (X, Y, and Z)
h. (1) 1-MHz reference
i. (1) carrier-operated-relay output
j. (1) remote-control interface (IEEE-488 or RS-232)

The complete performance test for the WJ-8618 receiver utilizes all the specification tests found in Table 1. Manual intervention in the end-to-end test process is virtually eliminated after initial signal interconnects are made to the ATE hardware. Although there are 22 specification test algorithms, many of the tests are repeated using different test parameter values so as to validate the full range of the receiver. The entire end-to-end test utilizes approximately 60 specification tests.

Diagnostic analysis is initiated when a given receiver specification falls out of an acceptable range. Figure 3, a WJ-8618 test-flow diagram, displays a single default branch originating from a frequency accuracy specification test. The SPEC test performs a frequency accuracy check on IF bandwidth number 5 (1 MH) of the WJ-8618B; a synthesized signal generator supplies a 115 MHz rf signal to the rf input of the receiver. A 21.4 MHz ± 30 Hz IF signal should be counted at the receiver IF output port. If the IF is measured to be out of range, then fault isolation is required to one of five CCAs. The diagnostic branch in Figure 4 will isolate the fault to either the first converter (A3A6), second converter (A3A7), IF amplifier (A3A9), or the am demodulator (A3A16). The first node checks the first converter section by prompting the operator to perform a signal probe (SP) measurement for 550 MHz ± 30 Hz on A3A6 J3. If that frequency is not counted, then the operator is prompted to replace A3A6, first converter. If the SP test passes, testing continues down the left branch of the diagnostic tree. As shown in Figure 4, each node prompts the operator to perform SP tests until a failed CCA is identified.

This concept reflects standard troubleshooting logic found in some manual test procedures. However, all instrumentation setups for SP tests are automatic and all decisions are made by the test program set rather than the operator.

Manually performed end-to-end specification tests on the WJ-8618 and similar receivers require 12 or more hours of technician time. The complete automated test using the WJ-1550 decreases that test time to approximately 30 minutes.

Conclusion

RF ATE system solutions offer cost-effective alternatives to manual communications equipment repair. While many of today's communication systems vary in implementation, recognition of common characteristics between equipment should drive rf ATE system design. Test functions for these common characteristics can be shared among test programs, thereby reducing program development costs. Advanced software features reduce development costs, and increase the productivity of automated rf test systems.

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Notes