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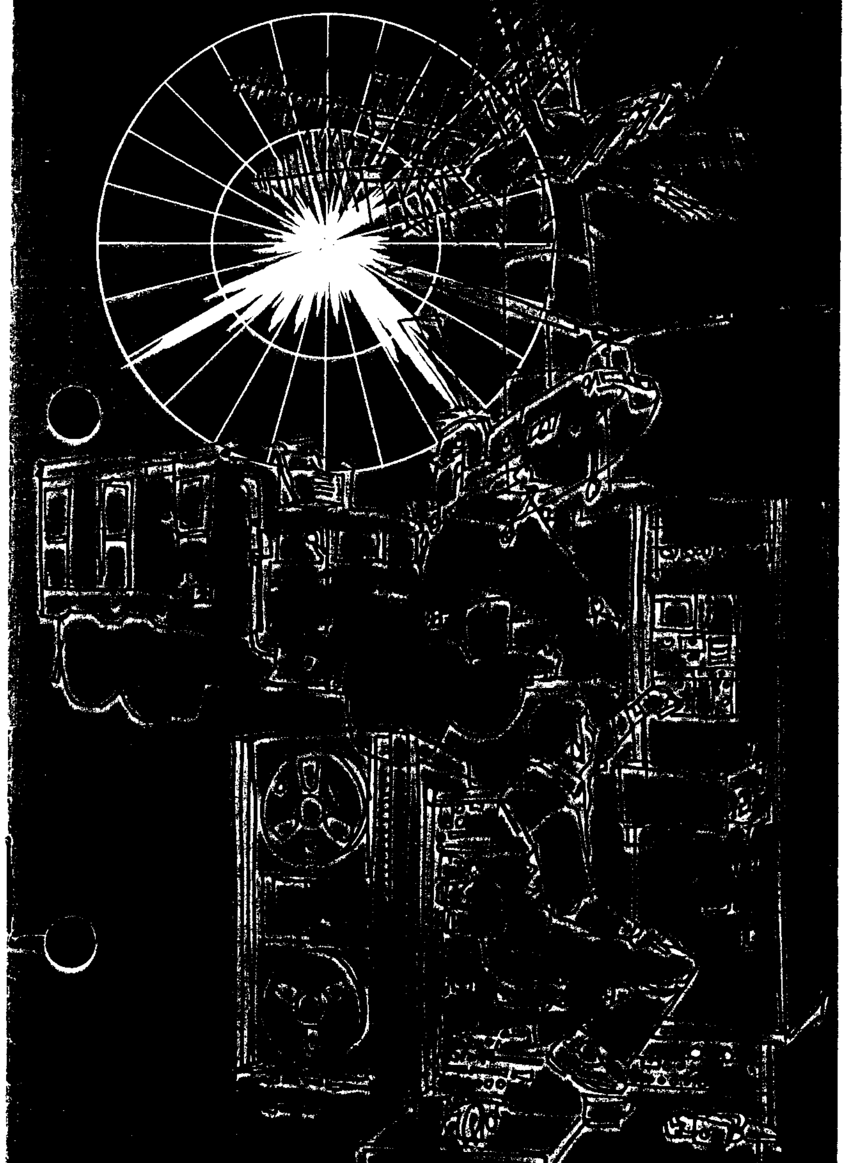
Tech-notes

ADVANCES IN MICROWAVE RECEIVER TESTING



WATKINS JOHNSON

Manufacturing and Office Locations

United States

SALES OFFICES

CALIFORNIA
Watkins-Johnson
3333 Hillview Avenue
Palo Alto 94304
Telephone: (415) 493-4141

Watkins-Johnson
831 South Douglas Street
Suite 131
El Segundo 90245
Telephone: (213) 640-1980

DISTRICT OF COLUMBIA
Watkins-Johnson
700 Quince Orchard Road
Gaithersburg, Md. 20760
Telephone: (301) 948-7550

FLORIDA
Watkins-Johnson
325 Whooping Loop
Altamonte Springs 32701
Telephone: (305) 834-8840

MARYLAND
Watkins-Johnson
700 Quince Orchard Road
Gaithersburg 20760
Telephone: (301) 948-7550

NEW JERSEY
Watkins-Johnson
90 Monmouth Street
Suite 207
Red Bank 07701
Telephone: (201) 842-2422

MASSACHUSETTS
Watkins-Johnson
5 Militia Drive
Suite 11
Lexington 02173
Telephone: (617) 861-1580

OHIO
Watkins-Johnson
2500 National Road
Suite 200
Fairborn 45324
Telephone: (513) 426-8303

TEXAS
Watkins-Johnson
9216 Markville Drive
Dallas 75243
Telephone: (214) 234-5396

International

ITALY
Watkins-Johnson Italiana
S.p.A.
Piazza G. Marconi, 25
00144 Roma-EUR
Telephone: 59 45 54
Telex: 60117
Cable: WJROM-ROMA

GERMANY, FEDERAL REPUBLIC OF
8033 Planegg
Watkins-Johnson
Münchener Strasse 17
Telephone: (089) 859-9441
Telex: 529401
Cable: WJDBM-MUENCHEN

UNITED KINGDOM
Watkins-Johnson
Shirley Avenue
Windsor, Berkshire SL4 5JU
Telephone: Windsor 69241
Telex: 847578
Cable: WJUKW-WINDSOR

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A Modular Approach to Diverse Stimulus Requirements

Microwave receiving systems require numerous tests during their original manufacture, operational usage, and maintenance. These tests are necessary to confirm proper operation or to identify levels of degraded performance. Greatest confidence is achieved through injection of known RF signals and comparison of the processed information against pre-established standards. Other methods are available but are inferior in that they normally test only portions of the total system or confirm only indirectly that various parameters are within acceptable limits. For example, some tests are performed by stimulus injection at the IF level rather than at the RF level. As a result, a significant portion of the receiving system is not adequately tested.

Maximum throughput and efficiency are achieved if the tests can be done automatically. This is especially true of production test situations where many tests have to be performed repeatedly. The advantage of computer controlled automatic test systems is that they are capable of operating at speeds several orders of magnitude greater than that of a manual system. The benefits are threefold. First, the tests are accomplished in a fraction of the time and effort it would take to perform them manually. Secondly, larger tasks can be attempted that are otherwise too time consuming and too costly. For example, large data samples of a particular test parameter can be easily and economically taken. Finally, the possibility of human error during these tests is eliminated. Not only does this reduce extra effort, but it also adds to the credibility of the test results. Common to all these benefits is the long-term savings in labor. Additional cost reductions will be reaped as advances in system software are made so that a technician-level operator can generate test programs.

Synthesized Signal Source

In addition to automatic control, other recent advances in microwave receiver test systems lie in the area of hardware. One of the most significant improvements in the latest receiver test systems is the use of a frequency synthesizer as the signal source. A synthesizer has numerous advantages over an ordinary signal generator; among the most important are the repeatability of frequency programming and the long-term stability. At constant temperature, a synthesizer with a crystal oscillator reference will have a long-term stability of about 1 part in 10^9 per day. This means that over a period of twenty-four hours, whenever the frequency is programmed to 1 GHz, for example, the repeatability of the output frequency is within 1 Hz. Another important advantage is that synthesizers are digitally programmable, whereas most signal generators are not. This is an important feature for computer-controlled systems, or for applications in which remote-controlled operation is required. Such systems facilitate the operation of the tests, especially for real time, on-line calibration tests. Operators no longer have to shuttle between the RF hardware at the remote site (often high atop an antenna tower) and the base control location during a mission, thereby saving time and effort.

Increased frequency coverage is another improvement in receiver test-system technology. Single synthesizers capable of covering a 100 MHz to 40 GHz range are currently available. This broadband capability gives the test system added flexibility in being able to handle various receiver systems over different frequency bands.

Greater use of solid-state technology in components has had a major impact on receiver test systems. Weight, size, and power consumption have been significantly reduced over that of older systems. Perhaps more importantly, the reliability and maintainability of the test systems have improved. Over the long run, these factors play a major role in the cost of receiver testing.

A better understanding of the applications of receiver test systems can be gained by examining specific cases. Three examples of receiver test situations are described in this article. One is a production test application, another is a maintenance/calibration situation, and the third example is an on-line operational calibration application. In each case, a test system was designed around a microwave frequency synthesizer and its ancillary units.

RF Target Simulator

For the production testing of direction finding (DF) receiver systems, it is necessary to simulate the signal environment in which the receiver is designed to operate. In one particular example, the DF processor uses information from up to eight antennas to determine the direction of the unknown emitter. The processor also analyzes the signal for pulse modulation characteristics such as pulse width and pulse repetition interval (PRI). Initially, testing of these receivers was done manually by general purpose laboratory instruments. Consequently, the testing phase was a slow, tedious, and an expensive portion of the production. It was clear that an automatic test system would be more cost effective and, therefore, a special system for testing DF receivers, designated the RF Target Simulator, was designed.

The test system generates eight inter-related signal components, simulating the signal pattern that would be received from eight antennas. The receiving system under test must determine the direction of the target and characterizes the pulse width and PRI to within its specified accuracy. The sy[illegible]n computer produces a sequence of conditions, processes the desired information and provides an evaluation of the receiver performance.

Figure 1 is a block diagram of the RF Target Simulator System. Only the 2- to 18-GHz band is explicitly shown; the 0.5- to 2-GHz band is similar. The system can be broken down into five major subsystems: 1) signal source, 2) attenuator and pulse modulator, 3) microwave amplifier assembly, 4) signal divider assembly, and 5) system computer.

RF Stimulus Source

The signal source provides the basic CW stimulus, while the attenuator and pulse modulator assembly conditions the RF to generate the desired signal. The microwave amplifiers are utilized to insure sufficient power level at the output of each channel of the power divider assembly.

The heart of the signal source is a Watkins-Johnson Model 1250 Frequency Synthesizer. Fundamental oscillator outputs are provided by RF sources covering 0.5 to 18 GHz in six standard bands. These plug-in modules are interfaced to the synthesizer through an interface module. Programming of frequency can be done manually through a front panel keyboard as well as digitally through a rear panel connector.

Pulse modulation and attenuation control are provided by the programmable attenuation and pulse modulation unit. This unit accepts the synthesizer output in six bands and switches the signal into a common line for the RF signal conditioning. Amplifiers external to this unit can be switched into the RF path, or can be bypassed. Following is a bank of bandpass filters for harmonic rejection. This is necessary to prevent the recognition of harmonics as a multiple target. In addition to the pulse modula-

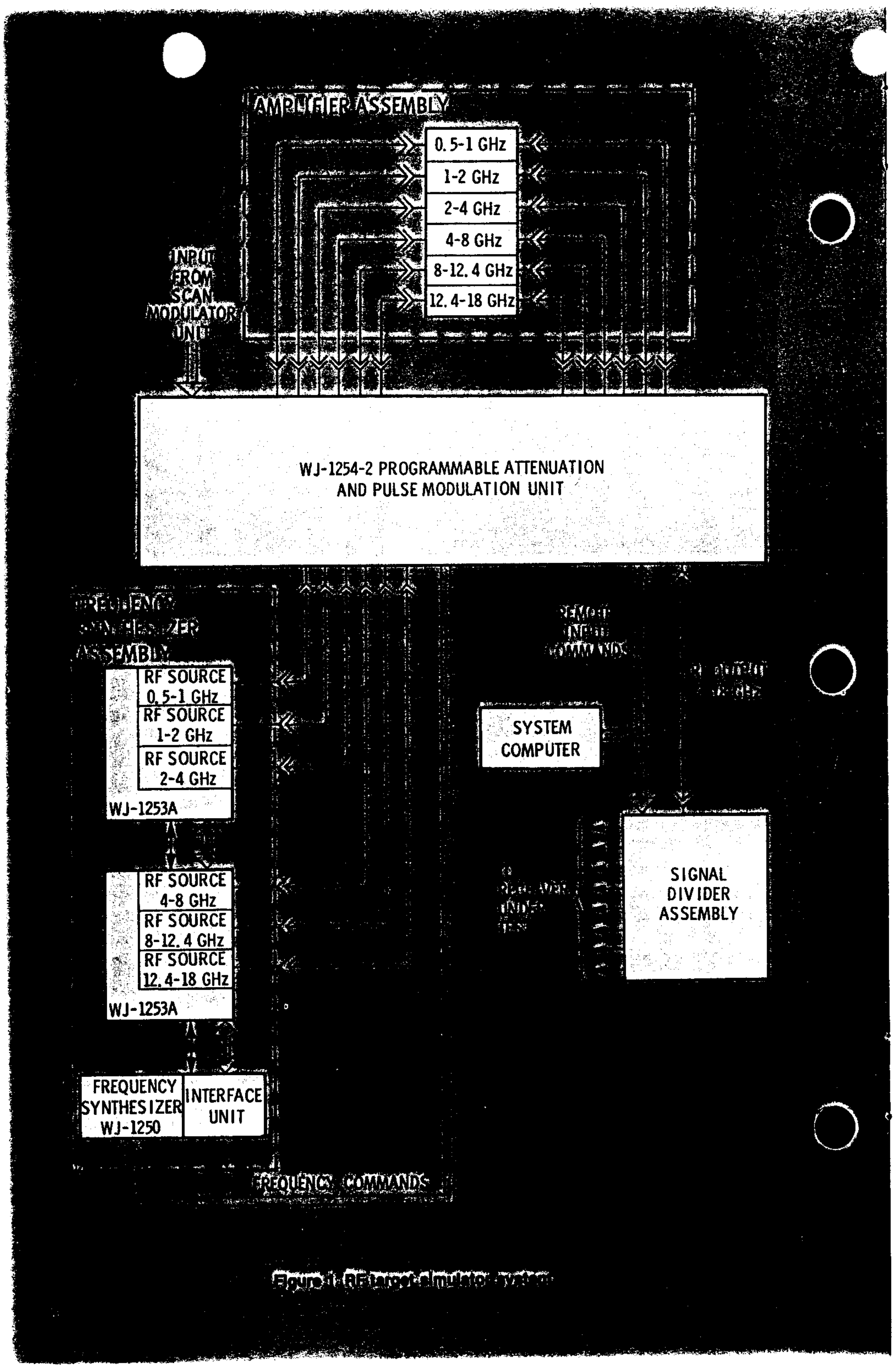


Figure 1. RF target simulator system

tion and the attenuation level control, the unit includes a digitally programmed PIN diode attenuator to simulate a radar scan pattern. Other features include provisions for monitoring a sample of the RF signal and for injecting an auxiliary signal into the system.

In the signal divider assembly, the RF signal is split into eight channels, each with independent attenuation level control. Any signal pattern can be simulated by the proper adjustment of the power levels in each channel, and by the programming of the appropriate pulse modulation parameters and attenuation level in the programmable attenuator.

System Computer

As shown in Figure 1, the system computer is the master controller. It programs the frequency of the synthesizer, the pulse modulation and attenuation functions and the RF switches in the programmable attenuator, and the attenuators in the signal divider assembly. After the computer has been given the program and the data, it commands the rest of the system to simulate the desired signal. Several advantages of a computer test system have been mentioned earlier. One concrete example of the power of a computer is a technique known as "software power leveling." In general, the power level at the output of the simulator system will vary with frequency. The computer can compensate for the frequency variation by an appropriate adjustment of the attenuators. This can be accomplished by a feedback loop in which power level is monitored and correspondingly adjusted by the computer to achieve the desired level. An open-loop method can also be used, whereby the computer stores a table of correction factors which it consults whenever a new frequency is programmed into the synthesizer. Of the two methods, the open-loop technique is the simpler to implement and was chosen for the RF Target Simulator System. ɔther configurations, a hardware leveling approach can also be used.

Table 1 lists the basic performance specifications for the RF Target Simulator System.

Radar Calibration

A second example of a receiver test system concerns a tracking radar maintenance/calibration application. Before and after the firing of a test missile, many hours are consumed in testing and calibrating the tracking radars along the missile flight path. At one island radar site, this test and calibration effort has been greatly reduced by the installation of a remotely-controlled synthesized signal generator system. Savings have been experienced in both man-hours of labor and the elapsed time needed for pre-mission and post-mission tests. An additional benefit has been the increased confidence in the tracking data obtained from this site. Two C-band radars are used to provide tracking data on test ICBM's fired from the U.S. mainland, as well as meterological rockets, satellites, and manned spacecraft which may pass within range. In order to be meaningful, the data on azimuth, elevation and distance has to be accurate to within very close tolerances. Therefore, the radar system is tested and calibrated before and after each tracking, and the data from this pre- and post-mission calibration process is maintained with the actual tracking data.

One portion of the test and calibration effort requires that a C-band signal be radiated from a fixed point to each radar antenna. Frequency, pulse width and pulse repetition interval are set as dictated by the target to be tracked. And, the radiated power level is varied to establish the noise floor and various calibrated points above it. Because both radar systems must be tested and calibrated in minimum time, and because redundancy in test

Table 1. Specifications for the RF Target Simulator System

Frequency Range	[illegible]
Frequency Resolution	100 kHz
Frequency Stability	[illegible] external ref.
Power Output (from WJ-1254-2) Primary Output (0 Attenuator setting) Unamplified w/100 MW Amplifier w/1 watt Amplifier Sample Outputs (2)	 [illegible] dBm min [illegible] dBm min [illegible] dBm min [illegible] dB relative to Primary Output Power
Harmonic Spurious	[illegible] dBc max
Non-Harmonic Spurious	[illegible] dBc max
Single Sideband Phase Noise	[illegible] Typical: [illegible]
Programmable Attenuation Range Linearity Repeatability	 0 to 79 in 1 dB steps ±2 dB max ±0.2 dB max
Programmable Pulse Modulation Pulse Repetition Interval Pulse Width Delay (Ext. Trigger Mode) Rise/Fall Time ON/OFF Ratio Trigger: Internal or External (TTL compatible)	 0.01-9.99 msec in 0.01 msec steps 0.1-999.9 μsec in 0.1 μsec steps 0.1 μsec-9.9999 msec in 0.1 μsec steps 20 nsec max 60 dB min
Programmable Scan Modulation: Range Programming (Remote Only)	 0-60 dB in 1 dB steps BCD Format, TTL compatible

systems increases the reliability of the site, two identical test source systems with antennas are employed. Figure 2 shows the physical relationship of the boresight tower, equipment shelters and radar vans.

The original method of generating the test and calibration signal was through use of a manually controlled signal generator located in each of the boresite shelters. This arrangement required that an individual travel over 1,000 feet to the shelter and adjust frequency, pulse width, PRI and attenuation under direction from the radar operator. This procedure was necessary for each source and radar pair, both before and after each tracking mission.

The solution to this requirement demanded that frequency, attenuation, pulse width, pulse repetition interval and system power be controlled from a distance of approximately 1,500 feet from the boresight shelters. In addition, attenuation was required to be highly repeatable, on the order of ±0.2 dB, and the other parameters had to be essentially equal to those of the signal generator. Figure 3 shows the complement of equipment necessary to satisfy the system requirements. Table 2 lists the basic characteristics of the system, while Figure 4 shows the relative position of each unit.

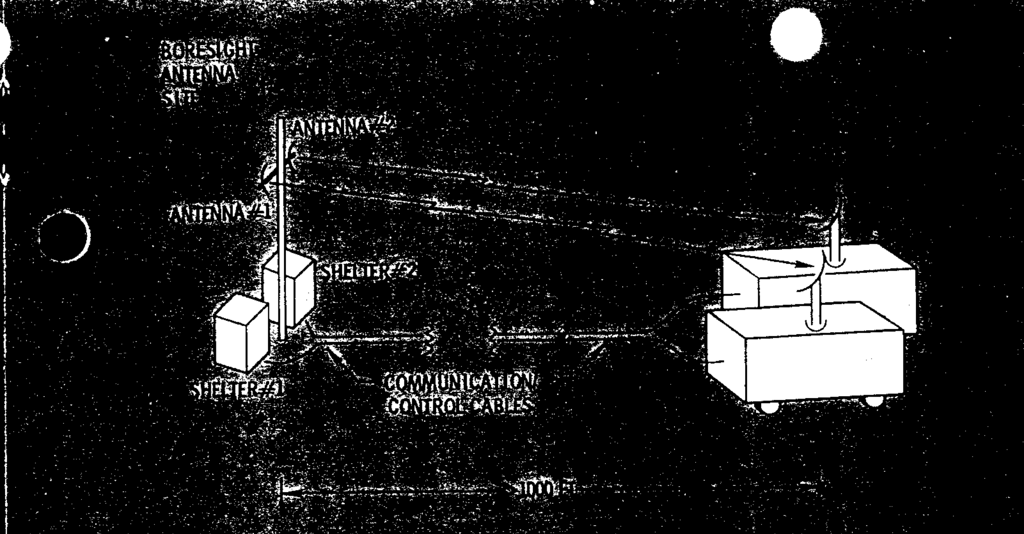


Figure 2. Radar test system site.

The synthesizer mainframe and RF source (4 to 8 GHz) provides the basic CW signal, while the attenuation and pulse modulation unit operates on the signal to provide the desired input to the boresight antenna. Frequency, attenuation and pulse width are manually programmable via the front panel keyboard and thumbwheel switches or, as required in this application, digitally controlled from the remote control unit located at the radar operator's position.

In addition to providing the serially

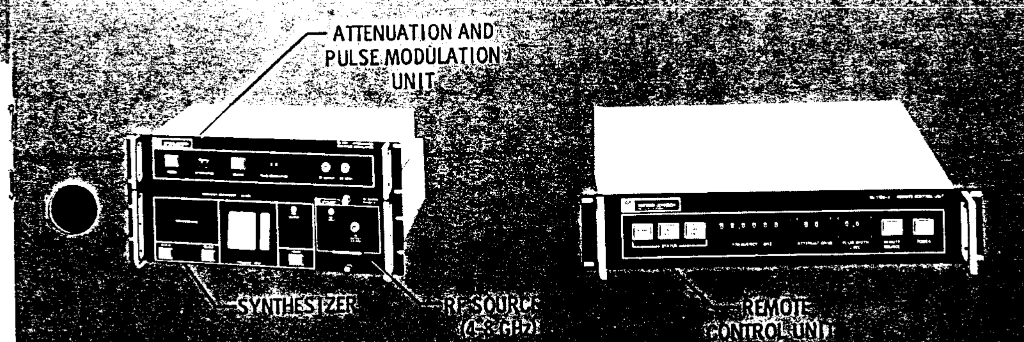


Figure 3. Radar test system equipment.

Table 2. Test System Performance Parameters

Frequency	Range	[illegible]
	Resolution	[illegible]
	Stability	[illegible]
Power output (CW, zero attenuation)		[illegible]
Attenuation	Range	[illegible]
	Resolution	[illegible]
	Repeatability	[illegible]
Pulse Width	Range	[illegible]
	Resolution	[illegible]
	Accuracy	[illegible]
[illegible]		[illegible]

transmitted frequency, attenuation, and pulse width commands to the frequency synthesizer, RF sources, and programmable attenuator, the remote control unit commands the main power to the test system and transmits the pulse modulation trigger signal from a source at the operator position. Control of the remote control unit is accomplished via its front-panel thumbwheel and push button switches or by digital input to its rear panel connector. The radar system computer will soon be employed to provide this input and truly automate this test sequence.

After approximately one year of operation, two test systems have been providing the anticipated savings of time and effort. In addition, the greater accuracy of the systems (relative to the original signal generators) has prompted plans for even greater usage than originally expected. The remote control capability justified the new systems, but the increased accuracy of the synthesized frequency and programmable attenuation allow the full value of the systems to be employed.

Receiver Operational Test

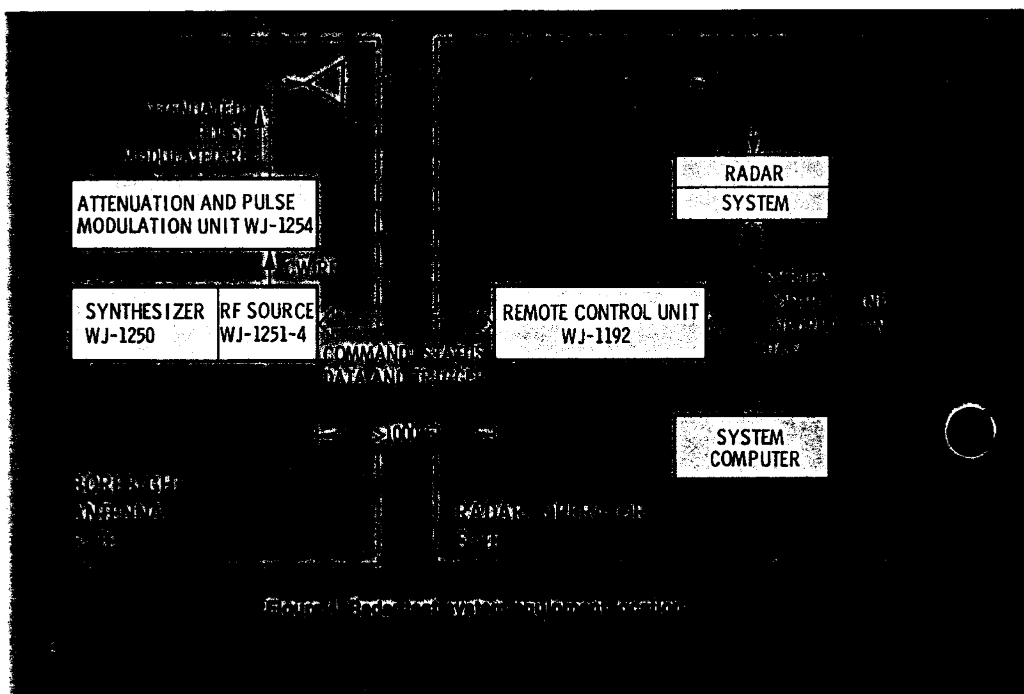
The third example of a receiver test situation involves a surveillance receiver system whose mission is to analyze and classify the short-term stability of incoming signals. The receiver system consists of an antenna and a set of octave band tuners mounted on a tower. The processing and analysis equipment as well as the system controllers are located at the base of the tower.

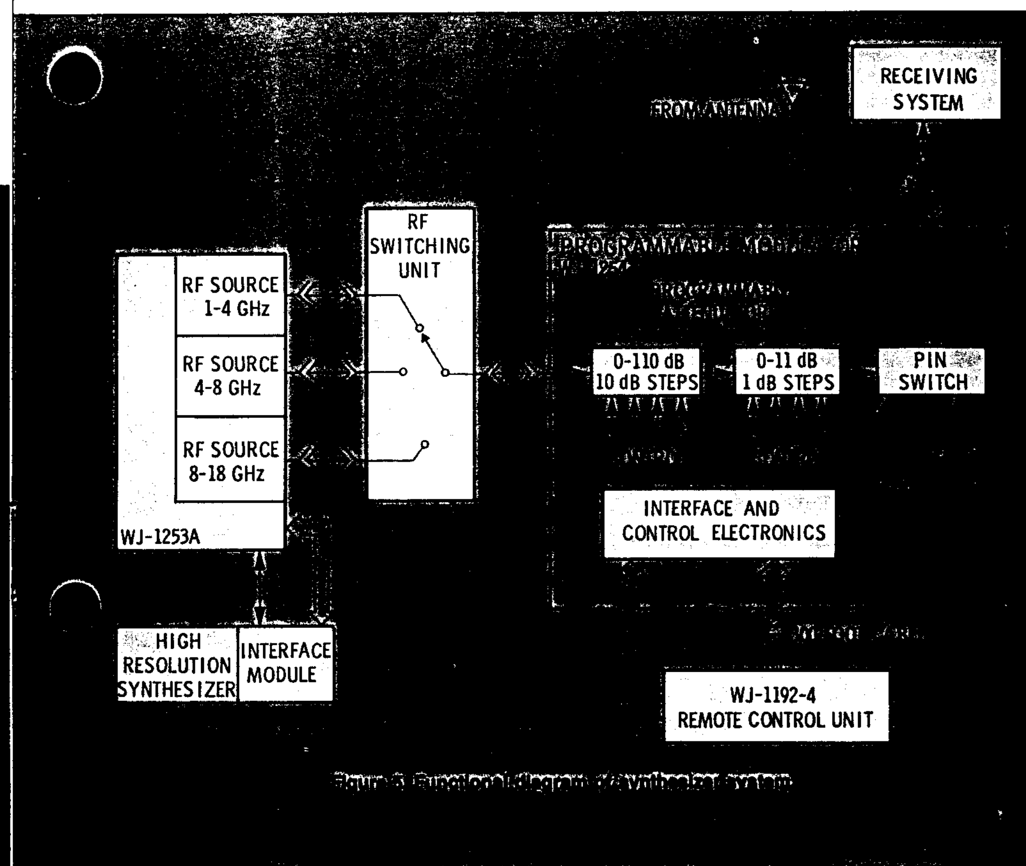
The technique for the stability measurement is to inject a signal with a known short-term stability into the receiver as a cali[illegible]ion against the incoming signal. The requirement for the calibration signal to have a short term stability of $5 \times 10^{-10}/100$ msec dictated the use of a synthesized signal source. Figure 5 is a functional block diagram of the synthesizer system.

The simultaneous requirements of short-term stability, broad frequency coverage (1 to 18 GHz) and 100 Hz resolution were met with a Watkins-Johnson Model 1255 High-Resolution Synthesizer.

The system is pictured in Figure 6, and Table 3 lists the performance characteristics.

The remote control unit is located at the receiver operator's console, while the rest of the equipment resides with the tuners on top of the antenna tower.





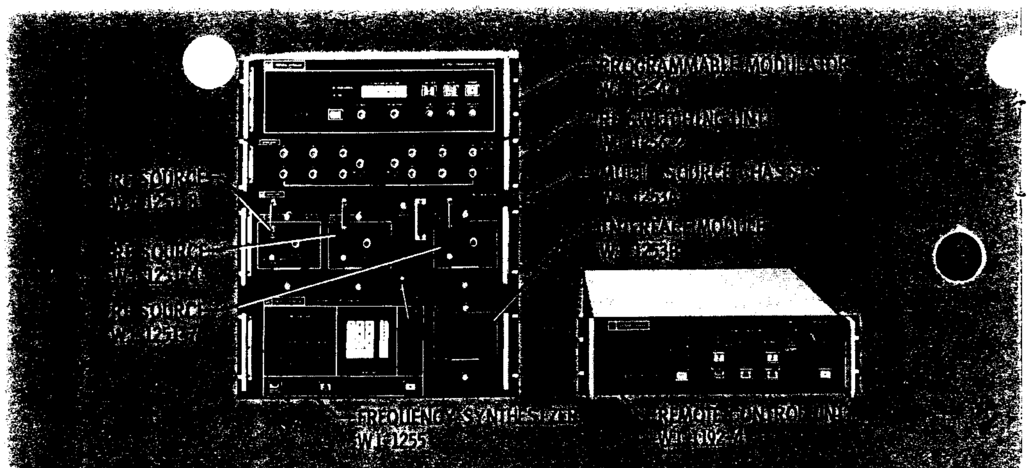


Figure 6. Calibration system

The remote control unit is capable of programming the synthesizer frequency and all the pulse modulation and attenuation functions of the programmable modulator. It also features a frequency slew control, whereby the synthesizer frequency can be scanned up or down in steps as fine as 100 Hz. The slew control became a useful feature in programming the synthesizer to match the frequency of the incoming signal.

Two factors that have emerged as the strongest features of the system are: 1) its excellent short-term stability and 2) its ease of operation. The frequency synthesizer typically has a short-term stability of 1 to 5 × 10^{-11}/100 msec. This gives the receiver analysis equipment a clean base-line from which to work. The broadband coverage, remote control capability, and the slew-control feature all contribute to the simplicity of operation. The ability to make real-time calibration tests from the operator's control console is a definite advantage during missions. Without such a sy[illegible], the missions would be more tedious, and less productive.

In all three examples given in this article, the use of a synthesizer-based receiver test system simplifies the testing tasks by reducing time and effort. In addition, the improved technical performance of the test hardware combined with the lower incidence of human error increases the accuracy of the tests. Test data can therefore be treated with increased confidence.

Table 3. Calibration System Performance Parameters

Frequency: Range	[illegible]
Resolution	[illegible] minimum
Stability	[illegible]
Short-Term Stability	[illegible]
Power Output (CW, zero attenuation)	
1 to 4 GHz	[illegible] dBm minimum
4 to 8 GHz	[illegible] dBm minimum
8 to 18 GHz	[illegible] dBm minimum
Attenuation: Range	[illegible] dB
Resolution	[illegible] dB minimum
Repeatability	[illegible] dB
Pulse Modulation	
Pulse Width	[illegible]
Pulse Repetition Interval	[illegible] steps
Delay (External Trigger Mode)	[illegible] steps
Rise/Fall Time	20 nsec maximum
ON/OFF Ratio	60 dB minimum
Accuracy	20 nsec or 5%
Trigger, Internal or External (TTL Compatible)	
Separation of Remote Unit	300 feet

Authors:

Charles E. Foster, II

Mr. Foster is currently Head of the Watkins-Johnson Frequency Synthesizer Section of the SSE Division. He is responsible for the design, development, manufacture, and sale of new microwave frequency equipment utilizing frequency synthesis and related techniques. Recent new developments include an RF Target Simulator System, the SN 105/WJ1740 Microwave L.O. Synchronizer and the WJ-1255 Microwave Synthesizer, all of which are digitally programmable and cover a frequency range of 500 MHz to 18 GHz, or greater.

Mr. Foster received a B.S.E.E. from Clemson University and an M.B.A. from Harvard University. He is a member of the Association of Old Crows.

Kenway J. Wong

Mr. Wong is currently working in the Watkins-Johnson Frequency Synthesizer Section with responsibilities for microwave synthesizer system and sub-system design and project management. He was recently project engineer for the High Resolution Synthesizer System which involved development of the WJ-1255 synthesizer, with special emphasis on state-of-the-art short-term stability specifications. He also was project engineer for the 0.5 to 18 GHz RF Target Simulator System for which he developed the WJ-1254-2 Programmable Attenuation and Pulse Modulation Unit. Mr. Wong has also been responsible for the development of Watkins-Johnson Company capabilities in the automatic microwave test systems field.

Mr. Wong earned an S.B. and S.M. from the Massachusetts Institute of Technology.