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Tech-notes

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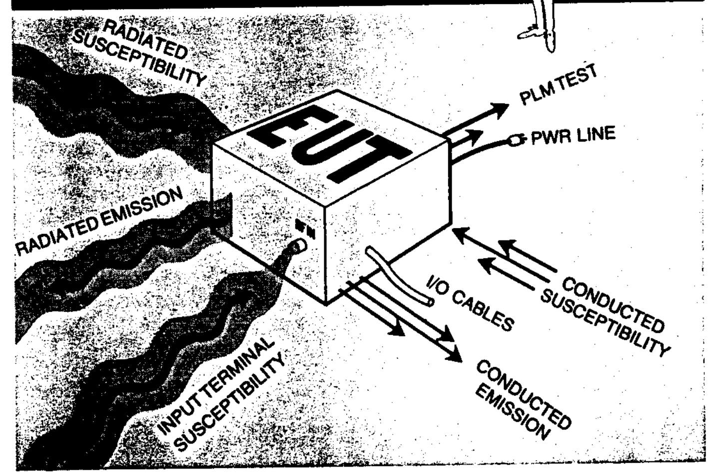
EMC/TEMPEST Detection Systems...

Test and Measurement Instrumentation



Electromagnetic compatibility (EMC) plays an important role in preventing environmental pollution of the electromagnetic spectrum. This natural resource is becoming increasingly crowded as man continues to design and fabricate modern-day electronic systems essential to our national security and well-being. Spectrum compatibility programs within the Department of Defense and other Government agencies are designed to ensure that electromagnetic interference (EMI) is controlled and compromising emanations (CE) are eliminated in military equipment design.

The ever-changing specifications and release of new standards creates frustration for the engineer who does not have time to stay abreast with EMI material. Certainly, it is disconcerting for newcomers to the EMI Community or others who must meet design requirements for the EMI/EMC and TEMPEST processes. These considerations are part of the interrelated topics brought together and described in this issue.

Electromagnetic Pollution

National emphasis today is on controlling and reducing environmental pollution. Today we recognize water, air, noise and other forms of pollution (man-made or natural). However, electromagnetic pollution is less recognized because it cannot be directly seen or felt.

Electromagnetic pollution is usually defined by terms such as radiation hazards, radio frequency interference (RFI), electromagnetic interference (EMI) and electromagnetic compatibility (EMC). (A description of terms relevant to the specialized fields of test and measurement may be found in *Tech-notes* Vol. 2, No. 6 November/December 1975, page 11.) These terms are all part of a more general problem defined as the effects of electromagnetic energy, both wanted and unwanted, and either radiated through free space or conducted through power and/or signal control lines.

Many elements of EMC concern were not intended to be radio-frequency (RF) emitters or receivers. Everyday devices we commonly come into contact with such as vehicle ignition systems, elevators, electric shavers, power lines, fluorescent lights, etc., often radiate electromagnetic energy although not specifically designed or intended to do so. Computers, electronic communications equipment, remotely-controlled devices, and other equipment are affected by the interception of this electromagnetic energy. A serious example of electromagnetic pollution involves persons with pacemakers who operate common electrical appliances, drive automobiles or come into contact with RF emitting sources which can cause the heart pacer to malfunction. Another example is the effects of electromagnetic radiation and its penetration into the human body, such as exposure to energy radiated from microwave ovens.

EMI Elements

The basic elements which produce an EMI situation (emanation) are an emitting source, transfer media, and receiver. Coupling from the source to the receptor may be achieved by either electromagnetic field coupling of radiation, or direct coupling by line conduction on power, signal and control lines, cables, etc. connected to the equipment. Elements which emit or are affected by radiated electromagnetic energy, whether so-intended or not, may be characterized by their spectrum occupancy. Spectrum signature measurements are used to indicate what signals are generated throughout the frequency spectrum.

An electromagnetic emanation is the addition of an undesired conducted or radiated electromagnetic disturbance to the desired electromagnetic energy, resulting in degraded intelligibility. Electromagnetic compatibility provides the capability for electronic equipments to coexist in harmony. In order to achieve this harmony, measurements must be taken to ensure the electronic equipment will neither cause nor receive harmful interference to or from other electronic equipment.

Electromagnetic compatibility characteristics of electronic equipment are important to prime contractors who design and develop intra-system hardware for use in laboratories, avionics, shipboard, in the field, or at user's station. An electromagnetic spectrum chart gives a better perspective of the already over crowded spectrum. The chart clearly shows the designated frequency assignments for those authorized communications sources which intentionally radiate.

Impact

The effect of electromagnetic pollution is readily seen in the frequency spectrum's utilization. Currently, the U.S.

- Department of Defense (DoD) and its tri-service agencies.
- National Security Agency (NSA)
- OTC, Department of Commerce
- National Aeronautics and Space Administration (NASA)
- Federal Communications Commission (FCC)
- FAA, Department of Transportation
- BRH, Department of Health, Education and Welfare

Table 1. Principle Government agencies involved in issuing policy regulation and control of EMI/EMC.

Government has authorized over 120,000 individual frequency assignments. In addition, each assignment may have hundreds of thousands of licensed users operating in the same geographical location. As this utilization increases, spectrum congestion problems and sources of unintentional radiation will increase significantly.

Since the frequency spectrum is a natural resource used by Government, industry and the consumer, the Office of the President has placed the responsibility on the Office of Telecommunications Policy (OTP) to provide spectrum management controls and policy regulations. A few of the principle Government agencies involved in issuing policy regulation and control of EMI/EMC are listed in Table 1.

Other agencies, such as the Interdepartment Radio Advisory Board (IRAC), provide national level coordination and registration with government and non-government organizations. The Federal Communications Commission (FCC) and the State Department, through the International Telecommunication Union (ITU), work closely with other foreign nations at the global level. International organizations, such as IRU and IEC/CCIR, tend to unify all requirements. The EMI/EMC test methods and limits as recommended by the International Committee for Radio Frequency Interference (CISPR) of the International Electrotechnical Commission (IEC) are used by most international trade countries.

EMC Standardization

The FCC was established to regulate and control radiation interference which interfered with non-federal Government services. It investigates and resolves cases of interference and oversees spectrum utilizaton. As communications equipment became more abundant, more complex, and utilized larger segments of the RF spectrum, the FCC has issued ten volumes of Rules and Regulations. Most of the consumer electronic requirements appear in parts 15 and 18 of Volume II.

An example of a VHF/UHF monitoring receiver currently being used by the FCC is shown in Figure 1. The receiving system (WJ-9026) consists of a receiver unit, a log/linear analysis display unit, and a frequency display unit with digital automatic frequency control. Combined, the units comprise a low profile receiving system that meets the needs for monitoring and measuring TV and radio broadcast signals over the 26-1000 MHz frequency range.

Even though a number of general purpose interference specifications were issued by the military services, it was not until the mid 1960's when the Department of Defense, the single largest user of the spectrum, issued a joint military EMI specification. MIL-STD-460 family of military EMI documents refers to the characteristic

Figure 1. An example receiving system (WJ-9026) used by the FCC to monitor and measure TV and radio broadcast signals over the 26-1000 MHz frequency range.

requirements and measurements of electromagnetic interference. The purpose of this standard was to provide military interference reduction requirements in a coordinated single series of documents. MIL-STD-461/462 have superceded over eleven EMC documents released by the Army, Navy and Air Force.

Expanding Role of DoD Testing

In its role for coordinating similar EMC test standards for other DoD agencies, the Department of Defense has institutionalized its standardization policies dealing with Communications Security COMSEC equipments and systems. These standards, better known as TEMPEST, specify test procedures for measuring an emanation's characteristic and signal limits to provide an acceptable degree of compromising emanation security. The tests are required for use by all military departments, federal agencies, and prime contractors who are concerned with either conducted or radiated emissions which may contain classified information.

TEMPEST are controlled laboratory test standards performed to the guidelines of NACSEM 5100, NACSEM 5112 and KAG-30A issued by the National Security Agency (NSA). NSA is the national communications security authority and the lead agency responsible for issuing all TEMPEST policies and controls. Since TEMPEST documents carry security classifications, they are available only to those firms who have current TEMPEST-related Government contracts. U.S. commercial firms may obtain copies of these documents through their Government Contracting Security Representative.

Scope of Standards

The field of electromagnetic compatibility measurements, including both EMI/EMC and TEMPEST testing, employs many of the same methods, procedures and equipment used in detecting, measuring and analyzing emanations. Data gathered as a result of following TEMPEST testing procedures may be sufficient to satisfy the compatible requirements for the Tri-Service Electromagnetic Interference Standard MIL-STD-460 family of EMI documentation. However, because of the differences in detail and information content, MIL-STD-461/462 data and testing procedures will not satisfy corresponding requirements of NACSEM 5100.

The following is a list of applicable reference documents for EMI/EMC and TEMPEST testing:

- **MIL-STD-461A**
  Covers requirements and test limits for measurements and determination of the electromagnetic interference characteristics (emission and susceptibility) of the equipment under test (EUT). Performs tests as outlined in MIL-STD-462, ensuring that energy levels propagated from the EUT by radiation or conduction do not exceed specified limits.

- **NACSEM 5100**
  Deals with methods of studying and analyzing all selected electromagnetic radiated and conducted emanations which may contain classified information generated, processed or transferred by the ETU. Simplified terms . . . analyzing detected signals for possible correlation by reconstructing the detected data for information content (waveform fingerprinting) and comparing the energy density spectrum.

Due to the classified nature of specific and detailed examples of TEMPEST experience, this article will combine TEMPEST testing with EMC testing.

EMC/TEMPEST Testing General Requirements

Prior to any laboratory or transportable (field) testing, a control test plan is

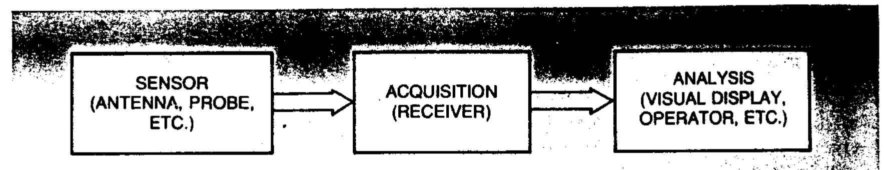


Figure 2. Elements of the basic tunable EMC Detection System.

submitted for approval which details the means of implementing the test procedures to be performed, including a listing and description of all intended receiving equipment to meet the test requirements. The equipment selected must be approved by the authority sponsoring the test, or have been certified under existing EMC specifications.

The general components of an EMC Detection System, as a minimum, must consist of three major functional elements: the signal sensing device (sensors), the acquisition device (receiver) and the identification capability (analysis), which may consist of an operator/device combination. Figure 2 illustrates the elements of the basic tunable EMC detection measurement system.

Technical information pertinent to a user selecting EMC detection equipment are the probe changes, sensitivities, gain variations, pre-detection and post-detection bandwidths and frequency ranges. These data can then be compared against the appropriate limits and bandwidth bounds of actual test requirements.

Components of a Typical EMC Detection System

The equipment under test subject to EMC testing is usually conducted in a controlled RFI environment, such as a shielded enclosure. Components of the traditional EMC Detection Test System are shown in Figure 3. The enclosure should be large enough to permit spatial freedom for test antennas in

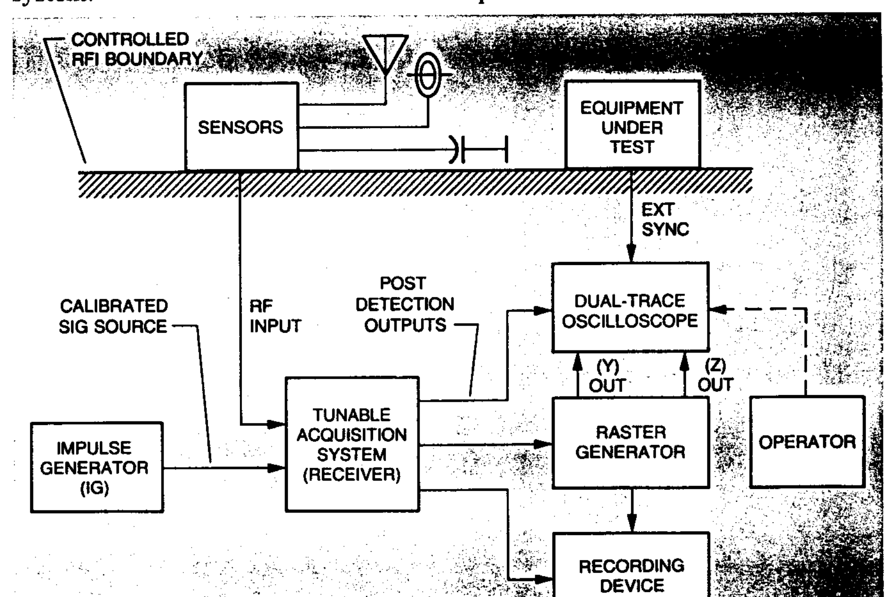


Figure 3. Traditional EMC Detection System.

both vertical and horizontal planes parallel to the EUT and chamber walls. The shielded enclosure should be tested and certified for an attenuation level to reduce ambient RF signals to a level equal to or below specified EMC limits. The signal sensing devices generally include appropriate active and passive electric (E) field and magnetic (H) field antennas, line impedance stabilization networks (LISN), and current probes. The antennas, complete with antenna correction factors, are designed especially for measurements in the shielded room environment.

Questions concerning the availability of antennas suitable for TEMPEST testing are frequently heard. The criteria being that the antenna be broadband in nature and have the appropriate calibration curves for antenna gain equal to or better than the minimum required signal level. Companies having EMC facilities will find their existing antennas adequate.

The acquisition device is a tunable superheterodyne receiving system which performs a search for all EUT ambient signals. The EMC receiver acquires the emanation and the operator performs various methods of signal analysis in order to correlate the detected signal, determine if information can be extracted, and if so, can it be correlated back to the EUT. The correlated emanation measurement is necessary to determine whether the detected signal's energy density spectrum is above the specified limit at the particular test frequency.

The identification group consists of an operator/device combination for the specific purpose of performing real-time measurement analysis and correlation signal operations. These equipments may consist of items such as a standard high frequency or digital processing oscilloscope, a transient digitizer, a raster or special purpose synchronization generator, an optical visicorder, a pen-type X-Y plotter and various other sifters, FFT's, and recording devices. With programmable calculator-aided instrumentation (minicomputer) and other peripherals commercially available, waveform processing, audio correlation, signal averaging and amplitude domain probability density measurement computation of the acquired signal can be performed.

In addition, the EMC test system should have a calibrated signal source for measurement of detected energy levels and data-related signature comparison. The signal source may be a synthesized sine-wave (CW) generator or impulse-type (IG) generator suitable for direct substitution type measurements. The IG is preferred as the standard because of its lower cost in comparison to CW generators, and its capability to produce an impulse-type calibrated output in dB microvolts per megahertz over the entire test frequency range.

Economics of Selecting EMC Test Receivers

Requirements for electronic system hardware to meet the electromagnetic emanation standards have almost become a vital necessity. Most EMC research and development testing facilities are finding it necessary to upgrade their inventory of EMC measurement instrumentation to facilitate TEMPEST receiver emanation measurement and analysis. The proponents for selecting the tunable acquisition receiving system (manual or automatic) should be weighed as to the anticipated use of selected equipment, magnitude of task, test limits, number of individual tests, length of schedule, type of testing (laboratory, field, or production), curative design and modification, operator-engineer test time and expense for control test plan preparation, and detailed report writing/documentation. Because of the ever-changing guidelines and requirements of TEMPEST testing in tunable broadband and narrowband frequency coverage, a need exists for a wideband manual receiving system, as well as a semi-automated and direct computer controlled receiving system for automated EMC/TEMPEST testing.

Manual Test Receiver

The savings in time, manpower, and graphical reporting costs could be substantial to a truly automatic EMC measurement system. The one time initial investment is greater than the traditional method of operator-cum-engineer technique of manual testing, and economics plays an important role in the selection of the EMC receiver system. When tunable measurements called for in a test plan fall within a limited range of broadband and narrowband test categories, or fall outside of economically acceptable limits, the manual EMC test receiver yields comparable results. An example of a manual TEMPEST detection system, the RS-125-17, that has been surveyed and deemed acceptable for TEMPEST testing is shown in Figure 4.

The RS-125-17 Manual Receiving System is designed around a series of modulator building blocks. It permits a few inexpensive viable approaches to meet the required TEMPEST measurement setup configurations. The system provides AM video, FM video, CW and pulse reception for detection and analysis of correlated electromagnetic emanations over a frequency range of 1 kHz to 18 GHz. Band/bandwidth requirements for broadband and narrowband TEMPEST testing are met by a series of demodulators with bandwidths ranging from 150 Hz to 50 MHz. A simplified block diagram of the basic TEMPEST receiving system is shown in Figure 5. The basic system meets most TEMPEST testing applications in the 1 kHz to 1 GHz frequency range and maintains the capability for system expansion as needs change.

The modular design of the integrated system has capabilities that enable it to be configured to meet a variety of TEMPEST tests applications. A typical TEMPEST receiver set up is shown in Figure 6. It is configured from the complement of RS-125-17 receiving equipment and performs narrowband tunable tests at frequencies through-

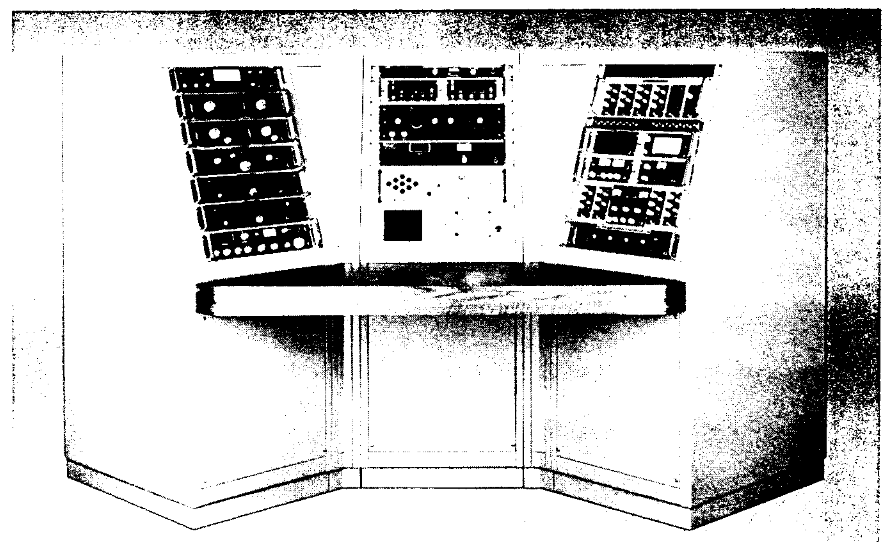


Figure 4. Manual TEMPEST Detection System (RS-125-17).

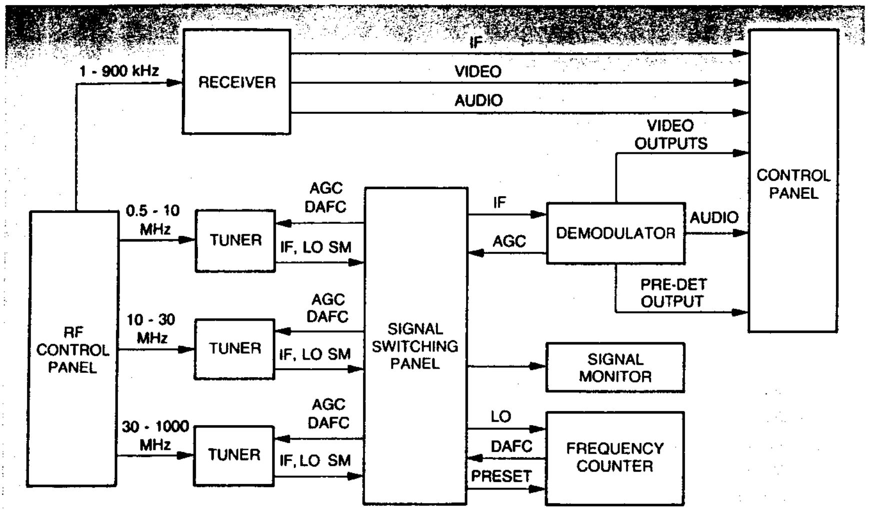


Figure 5. RS-125-17 basic TEMPEST receiving system, 1 kHz to 1 GHz.

out the 0.5–1000 MHz range. The selected tuner's 21.4 MHz IF is applied to the up/down converter. The up/down converter translates the IF signal down to 2 MHz which is applied to IF processor circuits in the receiver. The receiver demodulates AM, FM and CW signals through one of five selectable predetected bandwidths ranging from 400 Hz to 10 kHz.

Another variation providing a broadband TEMPEST receiver setup configured from RS-125-17 equipment is shown in Figure 7. RF input signals from the sensors are applied directly to the tuner, which tunes over the 30 to 1000 MHz frequency range in a single band. The wideband unit provides an overall IF bandwidth response of 50 MHz at the tuner's wideband output. The half-rack demodulators receive separate inputs from the tuner and provide AM, FM and pulse detection through their own selectable predetected bandwidths of 10/20 MHz and 30/50 MHz, respectively. Direct readout of the tuned frequency and LO stability to within 1 kHz for narrowband reception is accomplished with the frequency counter.

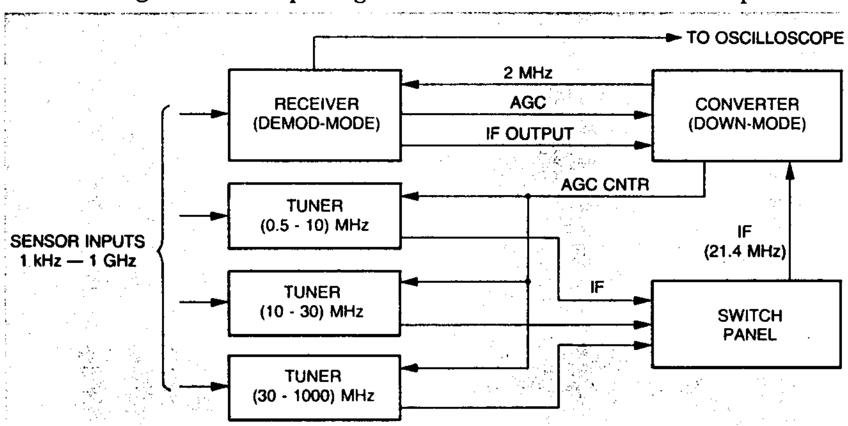


Figure 6. Typical narrowband TEMPEST receiver setup.

Semi/Automatic Test Receiver

In recent years, it has become increasingly obvious to the EMC Community that TEMPEST measurement requirements have begun to impose a heavy burden on traditional methods of testing. Automatic EMC measurements and graphical report writing are needed to handle the time-consuming tests and large quantities of data now required for pre-production qualification testing and production testing. For the user to select a semi-automatic/automatic receiver (acquisition) system over the traditional method of manual receiver operation, he must assess his capital equipment investment against the project, plan ahead and phase out old equipment, and weigh the long-term cost savings against the obviously high cost of a new start.

The semi-automated receiver is a system that will automatically perform a given function once the control functions have been manually set. To interrelate and control the various equipments of an automated EMC receiver system, the minicomputer and small desk-top calculator have been introduced to EMC measurements. Easy to use software programs can now be written to control and operate various pieces of EMC instrumentation required in a truly automated EMC measurement system. The addition of software to hardware gives an increase in hardware utility.

The automatic EMC receiver system can best be described as an integral part of a computer controlled measurement and analysis system that can be preprogrammed to carry out a complete test plan after applying the initial command. To achieve total automation, the computer-controlled receiving system must include software compilers that will be flexible enough

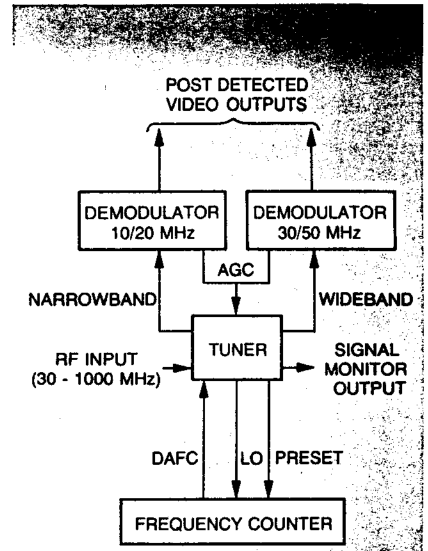


Figure 7. Typical broadband TEMPEST receiver setup.

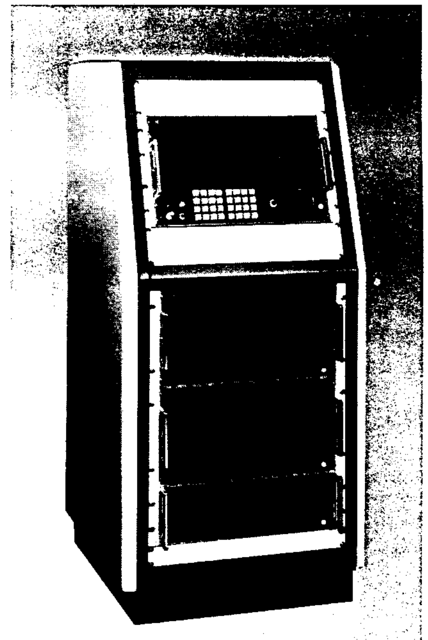


Figure 8. A microprocessor-based receiving system (WJ-8940B) which consists of a digital control unit, tuner synthesizer unit, IF/demodulator unit and a power supply unit.

to make the system capable of performing automatic EMC measurements while the equipment under test is operated in all modes. The software provides interactive programs to control the acquisition (receiver) and analysis hardware for determining the information content of signals of interest. The on-line computer should be able to print out a test plan for operator review and test file critiquing, display specification limits, plot minimum discernible signal (MDS) and frequency domain measurements, calculate antenna (sensor) correction factors, provide data reduction analysis, alert operator to deficiencies, and process data for final report editing which graphically prints out tabulated results.

A new generation of building blocks to meet automated TEMPEST/EMI measurement requirements is the WJ-8940B Multi-Purpose System shown in Figure 8. The unit is a microprocessor-based receiving system that provides all functions required in an automatic data acquisition and analysis measurement system. A microprocessor-based digital control unit controls all I/O system functions. The tuner and synthesizer units provide tuning over the 5 kHz to 1000 MHz frequency range. The IF and demodulator unit provides 17 bandwidths ranging from 200 Hz to 50 MHz and demodulates AM, FM and CW signals with peak, average and quasi-peak detectors as a standard. A power supply unit provides the necessary operating voltages to all the equipments contained within the receiving system with sufficient reserve power for system expansion. Automatic calibration and sensor selection provisions previously available in the WJ-8940A are retained in the WJ-8940B. Improvements of the WJ-8940B are listed in Table 2.

- Digital control unit containing an integrated LSI-11 microprocessor using same assembly language supported in DEC's PDP-11 family of computers.
- CRT-keyboard control for inputing-outputing receiver functions.
- Mass storage interface capability (disk, tape, etc.).
- Improved semi-automatic operation. Commonly used set-up scans, start, stop, step size and center frequency may be entered via the keyboard.
- Digitally controlled output to drive a digital plotter. Alphanumeric and graphic programs for graphical reporting.
- Optional frequency coverage extended down to 20 hertz to meet the low frequency requirements of TEMPEST/EMI testing.
- Provisions for the addition of a narrowband IF/demodulator unit with bandwidths of 2, 5, 10, 20, 50 and 100 Hz.
- Use of 2175 MHz first IF to provide optional bandwidths of 500 MHz at 1 GHz.
- Synthesized LO tuning in 10 Hz steps from 5 kHz to 1 GHz.
- Hewlett-Packard compatible on 16-bit I/O interface.

Table 2. Features of the WJ-8940B Multi-Purpose System.

EMC Development

This issue has concentrated on the three essential EMC detection system components, i.e., signal sensing devices, acquisition devices and identification capability. Requirements and test limits for instrumentation used in detecting, measuring and analyzing electromagetic emanations are cited in applicable reference documents for EMI, EMC and TEMPEST testing (MIL-STD-461A and NACSEM 5100). As the EMC Community's experience with automated acquisition equipment grows, and as computerized analysis hardware development continues, numerous improvements can be anticipated with success measured by the cost savings that an automated EMI/TEMPEST measurement system will offer.

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Mr. Bellman joined W-J's CEI Division Application Engineering staff in 1972, and is currently responsible for the sales, customer liaison, proposal activities and programs for the Department of Army and USASA Offices in the Washington, D.C. area. His experience in the field of electromagnetic measurement techniques and instrumentation has contributed to the development of EMI/TEMPEST equipment. Mr. Bellman has authored articles on TEMPEST Detection Systems and the WJ-8940B Multi-Purpose System. Mr. Bellman received his AAS degree from the Capital Institute of Technology and is currently completing study towards his BSET. Mr. Bellman is a member of the IEEE, AFCEA and the Association of Old Crows.

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