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82-2601, Parts I and II

Automatic Test Equipment Calibration/Performance Verification Evaluation and Research Program (JLC/DoD Subtask 30702)

Part II

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Electronics and Electrical Engineering
Electrosystems Division
Washington, DC 20234

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Joint Logistics Commanders Panel on Automatic Testing
D Joint Technical Coordination Group for Metrology
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Thomas F. Leedy, Barry A. Bell, Paul S. Lederer

U.S. DEPARTMENT OF COMMERCE
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William L. Gans, Robert E. Nelson

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Preface

The work described in this report was performed in response to a request by the Joint Logistics Commanders Panel on Automatic Testing (JLC/AT). The final report issued by the Industry-Joint Service "Automatic Test Project" (June 1980) strongly urged NBS leadership for the metrology and calibration support of automatic test equipment (ATE). The contents of this report are the results of an initial attempt to respond to this mandate.

As an organization, the National Bureau of Standards (NBS) has little experience with large, multi-function automatic test systems. The Bureau does not manufacture, procure, or use these systems. The strength of NBS is in metrology, and it is this strength that was applied to characterizing the performance of automated test systems. The work reported here is experimental in nature. It does not constitute an evaluation, certification, or endorsement of any equipment or systems. The experiment was to determine the feasibility of applying a portable calibration standard at the interface of third generation ATE. There was no attempt to technically evaluate the system measurement capability beyond what is reported.

Third generation ATE is characterized by extensive use of computer systems to implement signal generation and measurement within the equipment. The system software required to program the computer is generally "invisible" to the user of such systems. No attempt was made to understand the system software in detail. Errors in such software could cause apparent measurement errors. Additional software, the NBS test applications programs, were written in ATLAS to actually implement the measurement processes. Knowledge that the application software was completely error-free or performed exactly as was intended is not certain.

The choice of the automatic test system for this experiment (AN/USM-410 or EQUATE) was by mutual consent of representatives from the U.S. Army, Air Force, and Navy. This particular system seemed a reasonable candidate since each service used at least one such system and all could profit by the work. No attempt should be made to compare the results from the two test stations used in this experiment. This comparison would be unjustifed from several points of view. First, each service uses their test system in a different manner and for different purposes. The particular Army system tested is used primarily for testing field communications equipment; the Navy station primarily tests digital logic assemblies. Secondly, somewhat different maintenance and calibration philosophies are applied by the various services. Thirdly, the test stations are of different age, the Navy system being the oldest. The age of the particular machine impacts both its hardware and software and the maintenance experience used in its support.

It should be reemphasized that this work was entirely an experimental investigation of a limited nature that was performed on only two automatic test systems. Accordingly, any conclusions and recommendations in this report reflect this limited sampling. Nevertheless, the results are probably representative of many automatic test systems and demonstrate the value of using an "on-site" calibration support scheme to reveal potential measurement problems.

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AUTOMATIC TEST EQUIPMENT CALIBRATION/PERFORMANCE VERIFICATION EVALUATION AND RESEARCH PROGRAM

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Paul S. Lederer, and Robert E. Nelson

Abstract

This work describes an experimental approach to verify the performance of selected third generation automatic test systems. The approach consisted of careful laboratory characterization of two types of signal sources. One was a dc and low frequency ac voltage source covering the range of approximately 100 mV to 200 V dc, and 300 mV to 140 V ac rms over a frequency range of 100 Hz to 10 MHz. The second source was a precision time synthesizer used to generate pulses of known durations from 50 to 1000 ns. Both of these sources were used to verify the ability of two automatic test systems to measure ac and dc voltages and time intervals. The methods used to characterize these sources and the measurement results of applying the sources to the two automatic test systems are discussed in detail. Recommendations for future efforts to improve the measurement capabilities and traceability of automatic test systems are also presented.

Key words: ATE; automatic test systems; calibration; characterization; dynamic transport standard; evaluation; field calibration; performance test; third generation system.

1. INTRODUCTION

1.1 Background

Complex, high-speed ATE systems have unique calibration requirements by virtue of their wide dynamic measurement range, their ability to both supply and measure electrical signals, and their extensive use of computer technology and software for the control of the systems.

The Department of Defense (DoD) is especially concerned that ATE systems perform properly since such equipment is vital to assure readiness of weapons systems. Additionally, to comply with MIL-STD-45662, Calibration System Requirements, DoD needs the calibration of ATE systems to be traceable to national standards.

In recognition of the fact that automatic testing is an extremely complex and highly dynamic technology, a Joint Logistics Commanders Panel on Automatic Testing was established by the services in July 1979. The Panel identified over 80 technical tasks needed to achieve its goals. Task 30702, "Calibration of ATE," has the purpose to "determine and develop concepts (policies, standards, techniques, practices and procedures) for on-line and off-line calibration to verify performance of the DoD family of ATE, with a special emphasis to be placed on performance verification of third generation and later generations of ATE."

During Fiscal Years 1979 and 1980, several proposals addressing these particular needs were submitted by NBS to the JLC/AT. Approval was gained for an experimental project, to be carried out jointly by staff from the NBS Gaithersburg and Boulder laboratories, in the Center for Electronics and Electrical Engineering (CEEE). The activity and results obtained during FY 1980 and 1981 on this project are the subject of this report.

It should be noted that the application of NBS sources to automatic test equipment does not imply that the equipment is thereby traceable to NBS standards. The measurements described in this report represent experiments which were not performed with the statistical rigor of an NBS calibration service.

1.2 Coordination Between Sponsors and NBS, and Within NBS

In the discussions which led to the acceptance of the NBS proposal by JLC, it was agreed that representatives from the services would form a committee to help guide and monitor the NBS efforts and to provide the necessary service contacts. This committee was of vital importance in helping to gain access to military ATE systems.

As proposed, the NBS efforts were to cover two types of electrical parameters with work to be carried out at the Gaithersburg and Boulder laboratories where the necessary expertise resides.

In September 1980, a meeting was held at NBS Gaithersburg to discuss the critical matters relating to ATE calibrations, and the plans for conducting this project. The discussion included ATE testing and traceability strategies and the division of the technical responsibilities between the Electrosystems Division (Gaithersburg) and the Electromagnetic Technology Division (Boulder). It was agreed that the former Division would be responsible for ATE parameters related to dc and low frequency ac, while the latter would be responsible for fast waveform (pulse) parameters, with the possible addition of radio frequency and microwave parameters in future years.

2. WORK PLAN

2.1 Objectives

The basic goal of this project was the establishment of techniques to assure proper calibration of the ATE systems as used by the DoD.

Key objectives of this project for FY 1980 included:

(1) The selection of representative military ATE systems following consultation with DoD representatives; (2) site visits, selection of electrical parameters, and the formulation of plans for their on-site measurement and verification; and (3) the preparation of procedures and instrument packages at NBS laboratories to carry out such measurements.

The objectives for FY 1981 were:

(1) The procurement, testing, characterization, and calibration of instruments for the field testing of selected ATE systems; (2) the conduct of field measurements/verifications of ATE systems; (3) the analysis of data and assessment of station performance quality; and (4) the planning of a more comprehensive approach to ATE station performance verification procedures.

2.2 Approach

The primary elements of the technical approach followed the objectives stated above and can be summarized as follows. The first phase was the selection (and possible modification) and laboratory characterization of commercial signal sources. The selection of those sources was dictated by the choice of ATE system to be investigated (i.e., its voltage, frequency, or pulse measurement characteristics), as well as the availability at NBS of adequate capability for characterizing the sources. Commercial availability, price, delivery time, and portability aspects were also considered, as was computer control capability.

The second phase was that of field measurements and performance verification of selected ATE stations. For this purpose, calibrated sources with suitable interface adapters/connectors were taken to the ATE station. The station was programmed to measure and record a range of source output signals as applied to randomly selected pins on the station interface panel. In this approach, the ATE station treats the source as a typical unit under test (UUT).

The third phase was the evaluation of the field measurement data at NBS in the light of knowledge about the performance characteristics of the sources. Based on this, conclusions could be drawn as to the actual measurement capability of the ATE station. Additional observations about station operation during the field measurements were also to be compiled.

It was recognized that these field experiments would represent only a limited sampling of the measurement capability of selected ATE systems. Therefore, the fourth phase of the approach was the development of a more comprehensive proposed program for assuring better measurement capability and traceability of military ATE systems.

2.3 Selection of ATE Systems and Parameters

Based on a number of visits to various DoD ATE installations in the Fall of 1980 (described in detail in section 3 below) two basic decisions were made with the concurrence of DoD. The AN/USM-410 (EQUATE)[1] ATE System was selected for on-site testing and evaluation. The primary reasons for choosing this system were: (1) it is a third generation ATE system using sampling techniques for virtually all measurements and digital synthesis for most waveform stimuli; (2) it is used by all three services; (3) it measures/generates a wide variety and range of signals; and (4) it uses the IEEE Standard 416-1978 ATLAS language. Following this decision, efforts were made to obtain access to one or more EQUATE systems in each of the three services. With the help of the service sponsors committee, access was obtained to one Army and one Navy installation. An extensive ongoing workload at the selected Air Force installation necessitated postponing a field test of that particular EQUATE system.

Following the selection of the EQUATE system, test parameters were chosen based on the knowledge of its specified measurement capabilities, combined with knowledge of the output capabilities of potential signal sources. For the dc and low frequency ac work, it was decided to use dc voltages from ±100 mV to ±200 V and ac voltages from 300 mV rms to 140 V rms at frequencies from 50 Hz to 10 MHz. For the pulse work, pulse duration over a range from 50 to 1000 ns was selected as the initial pulse measurement parameter.

It should be noted that during the actual experimental work, both in the source characterizations and the field tests, it was not feasible to obtain data over the entire amplitude-frequency spectrum. Further details are presented in sections 4 and 5.

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[1] In order to adequately describe the systems and experiments discussed in this report, commercial equipment and instruments are identified by manufacturer's name or model number. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

3. INITIAL SITE VISITS TO ATE SYSTEMS

Early in the program, and with advice and guidance from the military representatives for JLC Subtask 30702, several suitable ATE systems were selected and visited by NBS personnel. It was considered desirable to visit at least one ATE system for each of the services in order to see the systems in operation, to talk to the personnel associated with the systems, become aware of the operational environment, and to become generally familiar with the hardware. These visits are discussed next in the chronological order in which they were made.

3.1 Visit to Navy ATE Systems at the Naval Air Test Center, Patuxent River, MD

On September 10, 1980, staff from both NBS laboratories visited Cerberonics, Inc., a consulting firm to the Naval Aviation Logistics Center, and also the Patuxent River Naval Air Test Center. At the first stop (Cerberonics), the old and new versions of the Navy's weapon system test station, CAT-III-D and CAT-III-D(V1), respectively, were discussed with staff of the Naval Aviation Logistics Center and of Cerberonics, Inc. The CAT-III-D (AN/USM-429) is a computerized automatic test station designed to perform end-to-end fault isolation testing of Navy avionic subsystems or electronic ground support equipment. The CAT systems are made by Grumman to support the F-14 aircraft, and basically consist of a number of programmable stimulus and measurement instruments controlled by a Hewlett-Packard minicomputer over a custom control/data bus. The primary application of the CAT systems is for digital circuit card testing and fault isolation in an interactive mode. The major differences in the new version, not yet completed, will be different stimulus/measurement instrumentation, newer and more sophisticated minicomputer hardware and software, and Manchester bus fault isolation via color graphics terminal display. There are 36 old version CAT-III-D systems in use in the field at present, which were deployed about 1974-75.

The CAT-III-D test station, which contains some off-the-shelf commercial components, is housed in a three-bay equipment rack with all components fully accessible from the front of the station. The stimulus functions of this second-generation ATE system are provided by a commercial pulse generator (HP-1900A) and a function generator (Wavetek 154). The measurement functions are carried out by a commercial multi-functional digital meter (HP-3450B) and a counter/timer (HP-5326A). This system was the first of several which were observed that employ a two-step calibration procedure. First, a set of "core" instruments is removed from the station and calibrated conventionally -- in this case the digital multimeter and the counter/timer. Then, a system verification and self-test program is run to check the other instrumentation against the core instruments and to verify the overall system operation. Grumman is in the process of doing a "calibration and measurement requirement study" for both CAT systems with the intent of generating a calibration procedure to be applied to the UUT interface plane compatible with both versions of CAT. As part of this study, Grumman is to provide a prototype interface plane calibration unit that will be programmable and probably contain sources (active circuits).

This system was also the first of several which were observed that use a number of "adapter boxes" between the multipin (528-pin) ATE interface plane and the particular UUT. In the case of the CAT-III-D systems there are about 90 such boxes, each supporting one or more individual UUTs. This is the most common solution to the problem of adapting, in some cases, hundreds of different UUTs to a single multipin ATE interface connector. Typically, both UUT drive power and test signals are routed through the interface connector/adapter box to and from the UUT.

Following this discussion, the NBS staff members visited the Patuxent River Naval Air Test Facility and were shown three different Naval ATE systems. In addition to an operational CAT-III-D, we saw a Hybrid Automatic Test System (HATS, AN/USM-403) and a Versatile Avionic Shop Test System (VAST). The HATS system, built by General Dynamics and programmed by Lockheed, is an analog/digital card tester and fault isolator. It operates with the ATLAS high level ATE language and contains almost no commercial off-the-shelf stimulus/measurement instrumentation. It is a third generation ATE sytem with programmable interface units (PIU) which, under computer control, either apply a stimulus to the UUT or feed the UUT output to the measurement system in the station. The latter is the Sampling Measurement System (SMS) which provides the functions of digital voltmeters, counter/timers, waveform analyzers, spectrum analyzers, and phasemeters under computer program control.

The HATS system is similar to the CAT systems in that it has a non-standard control/data bus (a Varian minicomputer and ATLAS compiler). The HATS system also has a multipin interface (160 universal pins, individually programmable as stimulus or measurement channels, and 160 pins dedicated to measurement only). Some additional pins for power supplies and other functions are also provided. The interface connector is an ITT Cannon Electric (DL 110959) with 2496 contacts. This system is used with a multitude of adapter boxes, and relies on a two-step calibration procedure. In this case the "core instrument" for calibration is a 16-bit D/A converter. Complete calibration of the HATS system is seldom performed because it is too difficult and time consuming. Also, according to the operators the system is very difficult to operate properly due to overheating problems in the "War Wagon," their term for the interface plane unit and associated circuitry.

Calibration information in the HATS specification (GS 12436) states in section 3.6.4 "... units requiring external calibration, including the internal standards, shall be readily accessible and removable ... minimum time between required calibrations shall be 1000 operational hours..." A hardware description (appendix A, section A-57) in reference to the SMS states "... A reference voltage calibration service is available in the PIU to provide an end-to-end calibration of any input." Finally, appendix C refers to an integral dc voltage reference, programmable with 16-bit resolution (0.003 percent accuracy). An ac reference source is said to be corrected by comparison to the dc voltage reference through an internal thermal converter.

The VAST system has been deployed since about 1967 and is the oldest station that was observed. It was also by far the largest, consisting of about 30 full-size racks of mostly non-standard instrumentation. It is controlled by a Varian minicomputer and is programmed only with assembly language. Built by PRD, there are three or four of these systems on each aircraft carrier and in numerous shore installations. It is used primarily for avionics system testing for the A7 and S3 aircraft. Like the CAT and HATS systems, the large number of adapter boxes actually occupy more space than the system itself. Also, like the CAT and HATS, a small number of core instruments are pulled periodically for external calibration, followed by a daily system self-test and verification program run.

3.2 Visit to Army ATE Systems at the Army Depot, Tobyhanna, PA

On September 12, 1980, the same NBS staff members visited the Army Depot in Tobyhanna, Pennsylvania. This depot is a primary maintenance facility for Army electronic equipment, as is the depot at Sacramento, California. The depot is under DESCOM (Headquarters at Chambersburg, PA), which in turn is one of the organizations under DARCOM (Army Material Development and Readiness Command) Headquarters at Alexandria, Virginia. At the site NBS staff were shown two of the Army's ATE systems, the EQUATE system (two versions)and the BIGFOOT system. EQUATE (AN/USM-410) systems built by RCA are used for analog/digital circuit card testing and fault isolation, and instrument testing and calibration. Both systems use a Data General minicomputer and peripherals, operate with ATLAS and have stimulus/measurement instrumentation for dc, ac, low frequency, pulse, and RF tests. At Tobyhanna there were two old EQUATE systems in operation and one new one, currently undergoing evaluation. Aside from a more sophisticated computer system, both versions of EQUATE are quite similar. As opposed to most of the Navy and Air Force systems, test and calibration programs are written for the EQUATE system on-site by Army personnel. Throughout the Army, these systems support about 22,000 different line items in the areas of communications and radar. EQUATE is similar in concept to HATS, being a third-generation ATE system, and interfacing with the UUT through a programmable interface unit (PIU) and/or through a dedicated interface unit (DIU).

The EQUATE station includes programmable standards for ac and dc voltage, resistance, and frequency. The outputs are available at front panel connectors as well as being available internally for calibration of the measurement subsystems. The programming language is EQUATE ATLAS. The station is capable of calibration and performance verification of certain stimulus/measurement functions. The calibration programs can be used with ancillary calibration standards if required to reduce long-term measurement system errors in gain, attenuation, linearity, frequency response, and quantization. EQUATE uses built-in programmable secondary standards which are removable for calibration in a standards laboratory. The system was initially conceived as a quality acceptance tool, hence the acronym EQUATE (Electronic Quality Assurance Test Equipment), to provide capability for performing quality acceptance testing of electronic devices and systems at a manufacturer's plant without resorting to sampling plans. The basic test system has the capability of performing diagnostic, fault-isolation testing, as well as performance testing.

The EQUATE systems, as configured at Tobyhanna, consist of a control subsystem, a 650-pin programmable interface unit (PIU), a dedicated interface unit (DIU), and an optional RF/microwave unit. Physically, the system contains five, 5-ft high rack panels plus control keyboard/CRT terminals. The specifications for the EQUATE station claim the capabilities of measurement of ac and dc voltages to 200 V with a maximum accuracy of 0.1 percent. The accuracy decreases with frequency until at 500 MHz the claimed accuracy is 4 percent. Measurements of current, resistance, and impedance can be performed, as well as frequencies up to 500 MHz in the basic EQUATE system, and up to 18 GHz using the optional RF/microwave unit. A wide variety of other test capabilities are available on EQUATE, including AM and FM modulation measurements, RF power measurements, spectrum analysis, network analysis, phase-angle measurement, and digital data measurements. All measurements are under computer control by which is claimed the capability of providing for calibration and performance verification of the system hardware stimuli and measurement functions. The test station has integral programmable secondary standards for ac (up to 1 MHz) and dc voltage (10 mV to 1000 V ranges), resistance (900 Ω to 9 MΩ), and frequency (5 MHz).

Another ATE system briefly examined was BIGFOOT (HP-9850), used primarily as a transceiver tester. Like EQUATE, it can perform tests for dc, low frequency ac, pulse, and RF, but, unlike the EQUATE, it consists almost entirely of commercial equipment, and operates with the IEEE-488 standard control/data bus. There are two such systems on site, one having just arrived. The ATE personnel seemed to prefer the BIGFOOT system to the EQUATE for transceiver testing, citing easier operation and higher UUT throughput.

3.3 Visit to Air Force ATE Systems at Eglin Air Force Base, FL

On September 17, 1980, NBS staff visited Eglin Air Force Base and were shown two of the Air Force's ATE systems -- the TEWS TITE system and a set of three older systems.

In terms of function, all four systems are used to support avionics in the F-15 aircraft. The TITE system is used for electronic warfare (EW) equipment, while the three older systems are used for microwave testing, on-board computer testing, and display testing. These systems reflect an AF philosophy of building ATE dedicated to supporting one particular weapons platform. Thus, the four systems seen are dedicated completely to support of the F-15 and are designed to be portable. They then go wherever the fighter wing is deployed, on short notice, along with the support personnel. The TITE system is built by McDonnell-Douglas, with Bendix and Honeywell as subcontractors. It consists of a Honeywell 316 minicomputer with peripherals, and a variety of commercially available stimulus/measurement instrumentation mounted in standard racks. Included are such items as a Digital Multimeter (Fluke 8375A), a Programmable

Pulse Generator (Wavetek 154), and a Programmable Digital Processing Oscilloscope (DPO) (Tektronix 7704A). The station has dc, low frequency ac, pulse and RF capabilities similar to the Army's BIGFOOT and EQUATE systems. It is programmed in assembly language (DAP-16) as well as ELAND. It has a multipin interface plane and numerous adapter boxes. The system is quite new and has not yet won the acceptance of site personnel. Three TITE systems, two in 24 hour/day operation and one currently being installed, were observed. As with all the ATE systems seen, the two-step, core-instrument approach to system calibration/verification is utilized. Also, like the EQUATE system, the RF/microwave section is a separate unit with its own interface plane, typically type "N" connectors, and must be connected externally to the UUT. The TITE system is the only one with a built-in DPO used as a core instrument. It was noticed that the stations contain a source of cooling air to cool the line replacement units (LRUs) under test to permit them to operate as they do in the aircraft.

The set of three older systems are really slight modifications of one single system. They all are built around a Bendix 6200 20-bit minicomputer system. Two stations are used for microwave testing, two for on-board computer testing, and two for on-board display testing. The systems are in continuous operation and have all been operational for several years. They appear to have many of their bugs already worked out, or accounted for, by site personnel.

3.4 ATE Problems Discussed During Visits

Among the objectives of the visits to military ATE stations was the uncovering of problems, primarily relating to measurements performed by the station. The information obtained is summarized in the sections below. It should be noted that station operating and supervisory personnel at all the installations were very accommodating in showing NBS staff the ATE stations and frank in discussing equipment problems.

3.4.1 Navy ATE

A problem in the CAT-III-D system is that the measurement devices are removed from the station for calibration and upon return are used to check the built-in function generators. This procedure has two drawbacks: first, there is no independent calibration or test of the function generators, and, secondly, there is no method of accounting for the effects of interfaces and cabling and switching networks on the measurements. These drawbacks pose a problem at the higher ac frequencies and at fast pulses such as are encountered at the 10 MHz bit-rate of the word generator. Interface device compensation is not done. There are about 90 different interface devices or boxes to connect the UUT to the ATE. It may be possible to calibrate, in-place, the measurement components in the CAT-III-D station with an external standard by running the system in its "wraparound" self-check mode. Normally, in this mode, the externally calibrated DVM and counter/timer core instruments are used to measure selected outputs from the function generator and the pulse generator to verify their proper operation in the station. Alternatively, by disconnecting these generators and applying stimuli from an external standard, the two measurement instruments could be calibrated in-place with appropriate changes in the self-check software. The advantage of this scheme is the availability of a wraparound test adapter box and an existing self-check computer program, both of which the Naval Air Test Center claims to have.

The major problem in HATS is heat buildup in PIUs which can actually damage the circuit boards. The HATS station at NATC is operated with rear panels open and an outside fan blowing air into the station. In addition, an exhaust duct removes hot air from the top of the station. Some calibration interface boxes for HATS permit the measurement of single parameters by providing access to dedicated pins. To run the calibration using a calibrated signal source would require writing a special UUT test program for this station. Additionally, a special calibration test adapter would need to be built.

3.4.2 Army ATE

A typical test sequence performed by the EQUATE system on a radio (TR-524) commonly used by the Army was witnessed. It was mentioned that there are approximately 25,000 of these radios deployed worldwide with about 5,000 sent to Tobyhanna for repair and alignment per year. A calibration of the radio takes approximately 25 minutes and includes sensitivity tests, frequency checks, and distortion measurements. The operating personnel have an annoying problem with interference being picked up by the radio from the keyboard/CRT terminal controlling the EQUATE system. This pickup makes the tests for receiver sensitivity nearly impossible, since in some cases the radio may receive more RF input from the terminal than it gets from the RF signal source supplied by EQUATE.

3.4.3 Air Force ATE

A wide variety of problems were discussed by TITE station operators and their managers. The problems include technical as well as managerial ones. It was pointed out that operator training is not adequate to assure effective operation of those stations. Station personnel commented that equipment is placed in service without adequate support. Very little consideration is given to auxiliary equipment -- no logic state analyzers, signature analyzers, and similar devices are supplied to help debug the stations. Since the conventional IEEE-488 bus is not used internally, future adaptation and modifications of the station will be more difficult.

Some of the units under test generate considerable amounts of RF interference, which can preclude the measurement of other low level signals by the station. Two other complaints cited were noise on signal ground lines, and the fact that the digital processing oscilloscope requires an 8-hour adjustment period after it is put back into the station following re-calibration. In general, calibration processes for TITE are considered to be in preliminary form only, and are considered to require clarification and elaboration. Ideally, one would like to require the periodic calibration of only certain core items in the station prior to station operational use. Some problems were experienced in the internal counter/timer when operated under software control.

Another universal complaint was frequently encountered during visits to other ATE installations and meetings with ATE people: the basic problem is perceived to be the lack of communication and interaction between weapons system designers, ATE station designers, and the metrologists concerned with the calibration requirements for the ATE stations.

3.5 General Observations From ATE Visits

Based on the above visits and discussions with site personnel, both military and industrial, a few general observations may be made. Although they are based on a limited sampling of ATE stations, these observations may be applicable to many such systems.

All of the systems seen had a few common features. They all allow the operator to connect the UUT to the ATE system, usually through an adapter box, and execute test or fault isolation programs from a keyboard/video display. They all use a multipin interface plane for dc, low frequency ac, and pulse stimulus/measurement connections to the UUT.

Differences in these systems, however, would present a number of problems in terms of establishing practical consistency with NBS standards. These include:

(1) Different stimulus and measurement instruments, including standard commercial devices, specially modified commercial devices, and custom-built instruments.

(2) Different, and inadequately defined, parameter ranges for stimuli and measurements.

(3) Different, and inadequately defined, accuracy and precision requirements. For example, the accuracy specifications as a function of operating environment for the ATE stations are often lacking.

(4) Different interface connectors, making it impossible to use a unique external standard without specifically dedicated connectors for each type of ATE.

(5) Different computer systems, software and memory media.

(6) Different control/data bus interfaces.

(7) Different degrees of software accessibility by the site (or NBS) personnel, and

(8) Different industry and site philosophies as to exactly what actions constitute an ATE system calibration.

Finally, the measurement uncertainties caused by the electrical characteristics of a multitude of undefined interface-plane adapter boxes could have significant impact on ATE performance. Such problems include possible ground loops, stray capacitances, RF pickup, cross-talk, and the generation of thermo-electric and other parasitic signals.

To be effective, a program for establishing techniques to assure proper calibration of ATE systems in DoD must address or consider all of these problems.

4. CHARACTERIZATION OF SIGNAL SOURCES

4.1 Selection of Sources

4.1.1 Selection of the DC to 10 MHz Source

An important part of this project was the selection of a stable source of dc and ac voltages that could be applied as stimuli to ATE stations under test. Several alternatives were considered which included the design and construction of a suitable source at NBS, the assembly of a package of commercial instruments that would provide the stimuli, and the use of a commercial meter calibrator. The last alternative was adopted since meter calibrators are available commercially and time restrictions did not permit the development of an NBS-designed package. One was identified as having sufficient range and accuracy to demonstrate the concept of a transportable standard that can be brought to an ATE station.

An advantage of using the meter calibrator chosen as a source is the ability to program its output in three ways: (1) the output can be manually controlled via a keyboard data entry system; (2) the output voltage can be selected by an internal tape cassette unit which is preprogrammed to provide various outputs; and (3) the desired output can be selected via an IEEE-488 interface. The IEEE-488 interface can select an output voltage in response to commands from a computer or instrument controller. All three data entry techniques were used with the source in this project. This source was programmed over an IEEE-488 bus for the collection of data that was used to determine the source stability. The tape cassette was programmed with the test sequences that were applied to the EQUATE stations, and the manual data entry system was used for program checkout and for debugging.

The manufacturer's specifications of the selected source for ac and dc voltages are given in tables 1A through 1C. One important objective of this project was the verification of the performance of the source under various environmental influences that might be significant in field use. For example, the accuracy of dc voltage and its stability were determined from 0.01 to 200 V even though the source can provide a wider range. The more limited range of verification was chosen to correspond to the measurement range of the EQUATE station. This effort was necessary to ensure that the calibrator would produce predictable outputs over the use and environmental conditions that would be encountered in the field tests at EQUATE stations. The procedures and results of each of these tests are presented in section 4.2 below.

4.1.2 Selection of the Pulse Source

The initial NBS tests of the EQUATE station to measure the pulse parameter known as PULSE DURATION required a commercially available, stable, portable pulse generator that could be used as a calibrated transfer standard. The unit chosen, called a "time synthesizer" by the manufacturer, has the following characteristics:

(a) Portable (<15 kg) and capable of being mounted in a standard 19-in rack environmental shipping container.

(b) Capable of being controlled by an IEEE-488 data bus.

(c) Digital control of pulse time parameters, as opposed to continuous vernier control, to allow accurate, repeatable parameter settings both in the laboratory and in the field.

(d) An accurate, stable internal time reference standard consisting of a 10 MHz crystal oscillator with a drift rate of $<5 \times 10^{-10}$ per day.

(e) An output pulse with amplitude variable from 0.5 V to 5 V, first and second transition durations (rise and fall times, respectively) of <5 ns, and pulse durations variable from 5 ns to 160 ms in 50 ps minimum step sizes.

(f) Absolute pulse duration accuracy of ±(1 ns + time base error) and a maximum jitter of 200 ps rms of the main pulse output with respect to the synchronization output.

This unit was procured in early 1981 for use as a prototype pulse duration transfer standard. Although the unit was controlled manually from the front panel for initial work reported here, it is anticipated that the IEEE-488 bus interface will be used for automatic control of the unit in the future.

4.2 Experimental Investigation of DC-10 MHz Source

4.2.1 Sensitivity of Source to Variations in Power-Line Voltage

The power-line voltage in industrial environments, such as sites where EQUATE stations may be located, is subject to change. Generally such changes are not large or rapid. However, the power-line voltage may vary several percent over a period of several hours. Thus, it was deemed necessary to explore the effects of power-line voltage on the output of the source.

The source was preset at the factory by means of a selector switch to operate at a nominal power-line voltage of 115 V ac. This switch accommodates various nominal line voltages. The specifications of the source apply at 115 V ac ±10 percent over a frequency range of 50 to 60 Hz. To verify that the output voltage of the source would remain stable over a range of input voltages, the following procedure was employed. The power line of the source was connected to an autotransformer which could vary the line voltage of the source from 0 to 140 V ac. A precision digital voltmeter was connected to the output of the source and output readings were recorded at various line voltage inputs from 90 to 140 V ac. This test range intentionally exceeded the ±10 percent specification limit of 115 V ac (103.5 to 126.5 V ac). The source was programmed to provide 10 dc voltages of plus and minus 0.01, 0.1, 1.0, 10.0, and 100.0 V dc. Figure 1 shows the results of this test. This plot gives the deviation of the output voltage of the calibrator, in ppm, from the nominal value observed at 115 V ac line voltage for each of the 10 dc voltages. The assigned uncertainty of output voltage due to line voltage is 25 ppm over a voltage range of -200.0 to -0.1 V dc and +0.1 to +200.0 V dc. The uncertainty assigned to the voltage -0.1 to +0.1 is 50 ppm. The largest deviations in the output were observed at the ±0.01 V dc levels. This probably resulted from temperature differences within the measurement system. During these tests a period of ten minutes was allowed after each line voltage change for the calibrator to reach thermal and electrical equilibrium.

Similar procedures were used to test the ac (rms) output stability of the source over the same range of line voltages. The source was programmed to provide output voltages of 1.0, 10.0 and 100.0 V ac at 100 Hz and 10 kHz. The uncertainties assigned to the output of the ac voltage due to line voltage is 150 ppm over all voltages and frequencies measured. Figures 2a and 2b show the observed deviations in ac output voltage at these two frequencies as a function of line voltage.

4.2.2 Long-Term Stability

To assure that the calibration of the source would be valid over an extended length of time, the stability of the source/voltmeter combination was measured for ac and dc voltages from January 26 through August 18, 1981. During this period, a total of 72 dc observations were made at an average interval of 2.8 days, using a programmable systems-type 6 1/2 digit meter. The meter was used in the mode claimed by the manufacturer to provide highest accuracy for a period of 90 days. In that mode measurement uncertainties are specified by the manufacturer to be less than 100 ppm on the 0.1 to 100.0 V dc ranges and less than 3400 ppm on the ac voltage ranges for frequencies from 50 Hz to 50 kHz.

Both the source and the voltmeter were programmed via the IEEE-488 bus to automate the data collection process. A graphic computing system containing 24 K bytes of semiconductor memory and an integral 300 K byte tape cassette was programmed to control the source and voltmeter during these tests. For example, dc voltages were monitored using a program that generates a sequence of voltages and measures each of the voltages ten times. The average, standard deviation, and average error of these ten readings were then recorded on a magnetic tape cassette. The sequence of voltages started at +0.00 V dc and progressed in 0.01 V dc increments to 0.1 V dc, then continued in 0.1 V dc steps to 1.0 V dc, and so on. At +200 V dc the sequence was reversed until -200 V dc was reached, then reversed again to return the source to -0.01 V dc. In this manner 154 dc voltage outputs of the source were measured and recorded on the tape cassette for subsequent analysis on the NBS central computer facility.

AC voltage data were collected in a similar manner except that five measurements were made at each of 63 voltage/frequency combinations. The test voltages ranged from 0.3 to 140 V ac at frequencies from 50 Hz to 50 kHz. Not all voltage/frequency combinations were tested since the maximum output from the source was 70 V ac at 20 kHz and 7 V ac at 50 kHz.

Figure 3 shows the errors that were recorded for a set of four different dc voltages over the seven-month test period. Using the data from 252 observations, a 3σ uncertainty of 55 ppm was assigned to the dc voltage of the calibrator as measured by the precision voltmeter over a seven-month period. The data shown for observation number 28 are not anomalies, but resulted from making voltage measurements when the source and voltmeter were not in temperature equilibrium. These measurements were made less than an hour after the instruments were exposed to low ambient temperatures during the field visit to Tobyhanna Army Depot.

Figure 4 shows the errors observed during the same seven-month period for four voltage/frequency ac outputs from the source. Over the seven-month period, 264 observations yielded a 3σ uncertainty of approximately 1720 ppm as measured by the digital voltmeter. In the next section, it is shown that, when measured by independent tests, the drift of both the ac and dc source was small compared to that measured by the voltmeter. It was thus concluded that the major drifts shown in figures 3 and 4 were due to a time instability of the voltmeter. It should be noted that there are six fewer observations for ac voltages than for dc voltages. This lapse in time (approximately ten days) was the time required to write and debug the software for recording and analyzing the ac time-stability data. Throughout this report the term "error" or "departure from nominal" is defined as that fraction:

$$\text{Error} = \frac{(\text{Applied Voltage}) - (\text{Observed Voltage})}{(\text{Observed Voltage})} .$$

When expressed in ppm, the fraction is multiplied by 10^6. The fraction is multiplied by 100 to express percentage error.

For both the ac and dc measurements, interconnection between the source and the voltmeter was made with a 6-ft length of RG-58C/U cable. This is the same length and type of cable used to interconnect the source and the ATE system during subsequent field tests. In addition, the traceability and distortion measurements described below were made at the end of the cable and interface connector combination, i.e., right at the output connector pins.

4.2.3 NBS Traceability of the Source

The dc output of the source was intercompared twice to the U.S. Legal Volt, maintained by the Electrical Measurements and Standards Division of NBS. This standard presently has an uncertainty of less than 1.0 ppm and intercomparisons are possible to this level. Normally, comparisons are made in the range of 0.015 to 10 V dc. The first comparison was made on March 19, 1981 to calibrate the source over a range of 0.01 to 10 V dc. Five months later, the source was again compared to the NBS Legal Volt to determine if the former had drifted significantly. For the second comparison, the calibration range for the source was extended to 200 V dc by special arrangement with the Electrical Measurements and Standards Division. The data obtained during both calibrations are shown in figure 5. From these data, 3σ uncertainty of 38 ppm was assigned to the time stability of the dc voltage source as compared to NBS standards over a range of 0.10 V to 200 V dc. The experimental apparatus used for these determinations is shown schematically in figures 6a and 6b.

The ac voltage of the source was measured as a function of amplitude and frequency by means of an NBS "Type F" set of ac-dc thermal voltage converter standards. The ac voltage to be measured is impressed across the heater which raises the temperature in a bead insulator and thermocouple. The resulting temperature change may be recorded by measuring the thermal emf of the thermocouple output. Next, a dc voltage is applied to the heater and its value is adjusted to give the same thermocouple output emf. If the ac and dc impedances of the thermal heater circuit are equal, then the dc voltage will be equal to the rms value of the ac voltage. The ac-dc difference tests consisted of determining the differences between the voltage required to give the same output from the thermal voltage converter standard on alternating current and on the average of forward and reversed direct current. The experimental arrangement used to implement the ac-dc transfer is shown in figure 6c. The ac and dc voltages of the source are available at the same output terminals by programming the source over the IEEE-488 bus. The output of the thermal converter is measured by the digital voltmeter, also controlled by the bus. In this manner, full control may be exercised over the generation and application of ac and dc voltages to the converter and over the recording of the resulting thermocouple emf voltages. A multiplier (current scaling) resistor, inserted between the source and the thermal converter, allows the thermo element to be used over a voltage range of 2 to 600 V ac.

Figures 7a and 7b are plots of the observed change in output of the ac voltage source on two dates approximately three months apart as determined by the ac-dc difference method. The voltage and frequency range of the data presented is 8 to 20 V ac, and 50 Hz to 50 kHz, respectively. From these 69 observations, the source was assigned a 3σ uncertainty of 93 ppm for stability over a three-month period.

4.2.4 Effects of Ambient Temperature

Changes in temperature can have a noticeable effect on the performance of precision electronic equipment. For example, both solid-state devices and precision resistors are susceptible to temperature changes. To investigate the temperature stability of the source, the unit was placed in a temperature-controlled chamber and operated at five temperatures. During the test, the air temperature in the chamber was monitored and recorded. After each change in chamber temperature, one hour was allowed to elapse for the source to reach the new temperature. Both ac and dc output voltages were recorded as a function of temperature from approximately 0° through +40°C. Figure 8 shows the limits of the change in output of the dc source over this temperature range. Over the 0° to 40°C temperature range, the maximum change in dc output voltage for all voltages measured was 180 ppm. Since the source was not subjected to more than a 5°C departure from the nominal 23°C reference temperature during any field test, the assigned uncertainty was conservatively estimated to be no greater than 40 ppm.

The ac temperature stability was measured in the same manner as the dc temperature stability. Figure 9 shows the changes in ac output voltage referenced to the output of the source at 23°C. The maximum change in the ac output voltage over all voltages and frequency combinations measured was 400 ppm over the temperature range of 0° to 40°C. The assigned uncertainty for ac voltage was estimated to be no greater than 80 ppm over the 23 ±5°C temperature range encountered in the field tests.

4.2.5 Start-Up Characteristics of the Source

The start-up characteristics of the source were investigated to determine the time required for its output to stabilize after turning on power. This information was necessary in order to allow sufficient warm-up time during field tests. The 10 V ac, 1 kHz output of the source was measured alternately with the output of a fixed 10 V ac, 1 kHz reference source. The reference source and the voltmeter had been powered continually for several days prior to the test at an ambient temperature of 22 ±1°C. This temperature was also maintained during the test. Both the source under test and the reference source were measured alternately, each 50.5 seconds for a period of 195 minutes (3.25 h). As the source heated during the warm-up period, the ac voltage increased in a manner similar to that observed during the temperature stability tests. Figure 10 shows the changes in output voltage of both the source under test and the reference source during the 195-minute time period. The graph is plotted such that the output of the source under test was set equal to zero ppm change at the time that power was applied. After 100 minutes, the source output voltage increased approximately 60 ppm and "tracked" the reference voltage. It should be noted that the initial measured output of the reference source happened to be below the average shown for the remainder of the plot. This difference has no significance and was unrelated to the output of the calibrator.

From the data shown in figure 10, it was determined that at least 90 minutes should be allowed for the temperature stabilization of the source under laboratory ambient conditions.

4.2.6 Distortion of AC Signals

The distortion of an ac signal is a measure of signal impurity. It is usually expressed as the percentage of the amplitude of the undesired components to the amplitude of the desired component, at the fundamental frequency of the signal. The total harmonic distortion (THD) expresses the ratio of total power in all significant harmonics to that of the fundamental. The power of the signal is proportional to the square of its voltage amplitude.

The distortion characteristics of the ac output voltage from the source were investigated using a commercial distortion analyzer. The analyzer removes the fundamental of the signal to be analyzed and measures the remainder. This resultant signal includes harmonic distortion and other components from noise or hum. The expression THD + N is normally associated with such measurements where THD refers to the total harmonic distortion and N refers to noise. The ac signal from the source was analyzed at eight frequencies and four voltage levels. The rms value of THD + N is shown in figure 11. No filters were placed in the signal path in making the measurements of the THD + N values. Thus, small amounts of residual voltage at the 60 Hz power-line frequency, typically about 50 μV, account for the increase in the THD + N values at the lower voltage levels.

These distortion measurements were performed to verify that the ac source complied with the manufacturer's specifications. However, since true rms measurements were always used to determine the amplitude of the ac signal from the source, the distortion of the signal did not contribute to an inaccuracy of the amplitude measurements.

4.3 Characterization and Calibration of NBS Pulse Source

4.3.1 NBS Automated Pulse Measurement System (APMS)

4.3.1.1 APMS Description

The system used to calibrate the PULSE DURATION source is the NBS Automatic Pulse Measurement System (APMS). A block diagram of this system is shown in figure 12. It consists of a minicomputer interfaced to a wideband (dc-18 GHz) sampling oscilloscope through a 14-bit A/D-D/A converter unit. In addition, circuits have been added to the sampling oscilloscope to allow asynchronous triggering of the sampler with respect to the computer.

The sampling oscilloscope is interfaced to the minicomputer and A/D-D/A unit in such a manner that it may operate either in a stand-alone mode or under computer control. In the stand-alone mode the oscilloscope has a frequency response of dc to 18 GHz, sweep speeds of 10 ps/cm to 5 μs/cm, an input voltage range of ±1 V, and a sampling trigger rate of up to 50 kHz. Under computer control the frequency response, sweep speeds, and input voltage range remain unchanged, but the maximum trigger rate is reduced to approximately 7 kHz due to the added time between samples necessary for A/D and D/A conversion and program instruction execution.

The minicomputer system is comprised of a computer mainframe, a flexible disk mass storage unit, a storage CRT terminal, a hard copy unit, and a paper tape reader and punch. The computer mainframe contains a 16-bit word length central processing unit (CPU), 64 K bytes of non-volatile core memory, peripheral interfaces, and a hardware floating point processor.

The latter reduces lengthy calculation times, such as for the Fast Fourier Transform (FFT), by a factor of 10 to 100. The flexible disk mass storage unit contains two disk drives providing an additional 500 K bytes of on-line memory for data and program storage. The storage CRT terminal, interfaced through a modified teletype port, runs in excess of 100 K baud. It operates in both an alphanumeric and graphic mode allowing a wide variety of information output formats. The hard-copy unit, either under manual or program control, produces a standard page-size paper copy of whatever is displayed on the terminal screen.

The system software, obtained from the computer manufacturer, is both sophisticated and versatile. Briefly, this disk operating system contains everything necessary for system operation with FORTRAN IV. The compiler, assemblers, loaders, editors, and libraries are all contained on flexible disks, as is an extensive package of diagnostic programs. From the user's or programmer's point of view, practically all programming, including graphics, is done in FORTRAN. The one exception is that the programs written to control the A/D-D/A unit must be written in assembly language as FORTRAN-called subroutines.

Referring again to figure 12, the system operates in the following manner. The D/A converter analog output is connected to the sampling oscilloscope time axis circuitry through a custom interface built into the oscilloscope. The analog voltage from the D/A converter controls the time at which the next voltage sample will be taken. Thus, a 0 V D/A converter output corresponds to a voltage sample appearing at the left-most oscilloscope screen graticule line and a full-scale (5 V) D/A output corresponds to a voltage sample appearing at the right-most screen graticule line. Effectively, then, the D/A circuit generates a computer-controlled oscilloscope sweep, normally (but not necessarily) from left to right.

The A/D converter is connected, again, through the custom interface to the voltage axis circuitry in the oscilloscope. As each voltage sample is taken, the converter's function is to digitize the sample voltage level and send it to the computer memory. With this scheme the oscilloscope screen has in effect been replaced by a 2^{14}- by 2^{14}- point signal recording grid.

The data acquisition programs, together with the digital logic circuitry in the custom interface, are designed to allow asynchronous triggering of the oscilloscope with respect to the computer clock. The oscilloscope trigger circuit, under interface control, locks out incoming signal trigger pulses until the A/D has converted the last sample, the D/A has settled to the next time position, and the A/D has been rearmed, in that order. At that time the next available trigger pulse causes a new sample to be taken. With this arrangement there is no need to synchronize the pulse generator with the computer program timing.

At the maximum trigger rate of 7 kHz, 1024-point time domain waveforms may be acquired and stored in memory in about 150 ms. In order to improve the signal-to-noise ratio, however, it is desirable to additively average a large number of waveforms (usually 10 to 1000). This signal averaging may be done either digitally in the computer or by use of an analog averaging circuit specially built into the oscilloscope. For additional information concerning the APMS see [1,2].[2]

4.3.1.2 APMS Time Axis Calibration and Traceability

In order to use the APMS to calibrate the portable PULSE DURATION source, it was first necessary to calibrate the APMS time and voltage axes. Immediately prior to each set of pulse measurements, the time axis of the APMS was calibrated using a commercial time mark generator. This time mark generator, in turn, was calibrated to within 1 part in 10^8 against the NBS (Boulder) 5 MHz national standard.

Referring again to figure 12, the time mark generator output was connected to the sampling head of the APMS such that a train of ten pulses (one per cm) was displayed and vertically centered on the screen of the APMS sampling oscilloscope. The sampling oscilloscope was then switched from the stand-alone mode to the computer-controlled mode and a program entitled TCAL was executed.

The TCAL program acquires an averaged 2048-point discrete signal representation of the pulse train and estimates the time between each positive slope or negative slope mid-screen crossing. A linear least squares curve fit is employed in the neighborhood of the mid-screen crossings to increase the resolution of the measurement. The time axis calibration factors, one for each centimeter on the screen, are then written to a disk file for use as correction factors in subsequent waveform acquisition programs. The short term (one day) overall estimate of uncertainty of these calibration factors is ±0.1 percent of the total time window or ±1 percent of the nominal time per centimeter.

The TCL program utilizes three subroutines entitled SOO, LINE and MATMUL. SOO is the waveform acquisition program and is written in assembly language. It is used to acquire the averaged 2048-point discrete signal representation of the pulse train input to the APMS and to store it as a floating point time series in the computer core memory for subsequent FORTRAN mathematical operations. Subroutines LINE and MATMUL, written in FORTRAN, are used together to perform the linear least squares curve fit of the data in the neighborhood of the midpoint crossings.

When TCAL is executed, an interactive dialogue takes place between the operator and the APMS. The terminal listing of a typical such dialogue is shown in figure 13. As indicated, the operator was asked to type into the system five variables. The first of these was the time mark generator output frequency, in this case 50 MHz. Next, the operator was asked for time calibration factors between sequential midpoint crossings of positive slope (type 1) or negative slope (type 0). Third, the operator was asked

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[2]Numbers in brackets refer to the literature references listed at the end of this report.

for the desired number of data acquisition sweeps to be generated to facilitate instrument setup. This program feature allows the operator to observe the actual data acquisition process under computer control and to make any last minute vertical or triggering adjustments before data is actually recorded. Next, the operator was queried as to the desired number of sweep averages to be recorded. The response shown, 200, indicates that each of the 2048 points in the recorded final waveform was the mean value of 200 actual samples taken at each time point. The last operator response was to indicate the desired number of data points in the neighborhood of each midpoint crossing through which the program is to fit a minimum-square-error straight line.

The program then computes the time calibration factors between each of the (straight line) midpoint crossings that it found in the time window. It then prints to the terminal and writes a disk file of these calibration factors, the applicable interval of each calibration factor, and the average time scale factor for the entire time window. Complete program execution time is approximately five minutes.

4.3.1.3 APMS Voltage Axis Calibration and Traceability

As with the time axis, the voltage axis of the APMS was calibrated using an oscilloscope amplitude calibrator designed and built by NBS for this purpose. This calibrator is essentially a stable, accurate dc voltage source with a range of ±1 V and adjustable in 1 mV steps. In addition, the source output resistance is switch selectable to <0.1 Ω, 50 Ω or 1 MΩ. Further information concerning this calibrator may be found in [3].

The amplitude calibrator was calibrated against an NBS (Boulder) 10 V dc standard to within ±0.05 percent of the calibrator voltage output setting. It was then used to calibrate the vertical axis of the APMS prior to each set of source pulse measurements.

The program used to calibrate the APMS vertical axis is entitled VCAL. With the amplitude calibrator connected to the sampling head of the APMS, and with the sampling oscilloscope set to a free-running trigger and computer-controlled mode, known dc voltage levels were sampled and averaged to yield a set of vertical scale factors, one for each centimeter of screen display. As with the time axis factors, these vertical deflection calibration factors were then written to a disk file for subsequent use as correction factors in the pulse waveform acquisition program. The short term (one day) overall estimate of uncertainty of these calibration factors is ±0.1 percent of the total (10 cm) voltage window or ±1 percent of the nominal voltage per centimeter.

As with the TCAL case, when VCAL is executed an interactive operator/system dialogue takes place, a typical example of which is shown in figure 14. As shown, the operator was first asked to type in the nominal vertical scale factor setting on the sampling oscilloscope (100 mV/cm) and the desired number of sweep averages (50). The operator was then instructed to set the amplitude calibrator output voltage (connected to the sampling head input) to the minimum desired voltage window value and then to position vertically the free-running horizontal sweep to lie on the lowest horizontal graticule line. When signaled (type any key), the system recorded 50 sweeps of 1024 points each and calculated the mean value of the 50 x 1024 points to yield one vertical voltage number. The operator was then instructed to increase the amplitude calibrator output by 100 mV (1 cm of deflection) and the above process was repeated.

After nine such repetitions were completed, the computer calculated the eight sequential first differences and scaled them to yield mV/cm vertical calibration scale factors for each of the eight visible centimeters of display on the oscilloscope screen. These values were then printed to the terminal, along with the mean of the eight values, and also written to a disk file for later use. Like TCAL, the complete program execution time is approximately five minutes.

4.3.2 NBS Pulse Source Calibration

4.3.2.1 Calibration Procedure for the EQUATE DIU Interface

Once the APMS time and voltage axes were calibrated in a manner consistent with NBS standards, it was used to calibrate the NBS/commercial PULSE DURATION source. Since the pulse source was to be used to test the ability of the EQUATE ATE station to measure the parameter PULSE DURATION, it was necessary to calibrate the source, as nearly as possible, at a reference plane electrically and mechanically matched to the EQUATE unit under test (UUT) reference plane. Because the EQUATE station has two such planes, the direct interface unit (DIU) and the programmable interface unit (PIU), it was deemed necessary to provide a set of calibrated PULSE DURATION waveforms for each of the two different planes. This section is concerned with the calibration of the pulse source for testing EQUATE through the DIU interface, while that for the PIU interface is discussed in the next section.

The problem of providing a known pulse waveform in the nanosecond/microsecond time range is primarily a problem of maintaining a known wideband impedance match from the generator to the measurement plane. From the Fourier transform it is known that electrical pulses with durations in the nanosecond range will contain frequency components that extend into the gigahertz range. For example, a "rule-of-thumb" equation often used to relate pulse duration to pulse harmonic content is

$$f_{co} \approx \frac{0.35}{\tau_d} .$$

That is, the 3 dB cutoff frequency, f_{co}, of the harmonic content of a pulse is about equal to one third of the inverse of the pulse duration, τ_d. As a consequence of the pulse time/frequency relationship, it becomes clear that the transmission of fast pulses requires the use of wideband electrical networks. If the intervening network between pulse generator and measurement plane does not present a matched impedance for all harmonic frequencies contained in the pulse, then the pulse waveshape at the measurement plane will be distorted.

The pulse generator output impedance is 50 Ω and the EQUATE station DIU is, in fact, a 50 Ω BNC coaxial connector so the problem of maintaining pulse waveshape fidelity at the DIU measurement plane was simply solved by using a 2 m length of 50 Ω RG-58C/U coaxial transmission line as a wideband interconnection. For purposes of testing the DIU, then, the pulse source was configured as the combination of the commercial pulse generator with a 2 m section of RG-58C/U connected to its pulse output port.

The EQUATE station is capable of measuring PULSE DURATION (often termed "time interval" in the manufacturer's literature) in the range of 20 ns to 10 μs. To evaluate the performance of the station, the pulse source was calibrated at nominal PULSE DURATIONS of 50 ns, 100 ns, 200 ns, 500 ns, and 1 μs.

Figure 15 is a block diagram of the equipment configuration used to perform the pulse source calibration for both the DIU and PIU measurement planes using the APMS. For the DIU case the output pulses from the time synthesizer pulse source were connected to the APMS sampling head via the 2 m coaxial cable and a Gaussian nine-pole low-pass filter (dashed line connection in the block diagram). This filter, designed and built by NBS, was inserted to smooth out the small perturbations in the output pulse waveshape caused by excessively high frequency components. In actuality, two such filters were used; one with a 5 ns nominal transition duration was used to smooth the 50 and 100 ns output pulses, while one with a 50 ns nominal transition duration was used to filter the 200 ns, 500 ns, and 1 μs pulses.

For purposes of calibration, the pulse source was driven by another pulse generator acting as a repetition rate clock. This external drive was necessary in order to provide a variable-delay trigger to the APMS. When used to test the EQUATE stations, this drive was unnecessary because the EQUATE uses a random sampling scheme precluding the need for a sampling pretrigger. In any event, the output pulse waveshape from the pulse source was unaffected by the triggering mode.

With the equipment configuration of figure 15, then, and with the DIU measurement plane defined as the BNC output of the Gaussian smoothing filter, the APMS was used to measure and record the pulse source output waveforms.

4.3.2.2 Calibration Procedure for the EQUATE PIU Interface

Attempting to provide a known pulse waveform to the EQUATE PIU measurement plane was somewhat more complicated. Physically, the PIU measurement plane is a zero-insertion-force (ZIF) 650 pin connector configured in such a way that signal pins and signal shield pins are interspersed in a checkerboard pattern. Behind each signal and signal-shield pin pair are I/O buffering and terminating electronics such that each pin pair can be switched-selected for use as a signal source port or a signal measurement port.

To provide a known pulse waveform at this PIU plane, it was necessary to connect the time synthesizer to the pulse filter and then connect the filter output to a PIU mating connector and calibrate the pulse output at that point. The filter-to-PIU mating connector interconnection was accomplished by modifying the individual PIU connector pins so that a BNC to twin lead custom adapter could be attached to any PIU connector pin pair. In order to connect the other side of the PIU mating connector to the APMS sampling head for calibration of the pulse waveform at the PIU measurement plane, a special twin-lead-to-SMA 3 mm coaxial adapter was constructed. Tests were then run to ensure that the twin-lead-to-SMA adapter contributed negligible distortion to the PIU connector measurement plane output pulse. These tests were necessary because this adapter was on the calibration measurement side of the PIU connector measurement plane (as opposed to the generator side) and would corrupt the calibration if poorly matched to either the PIU connector or the APMS sampling head.

Referring again to figure 15, the PIU calibration configuration (solid line) was the same as for the DIU except for the addition of the two adapters and the PIU mating connector.

4.3.2.3 Calibration Data Acquisition and Analyses

This section consists of four major topics. The first is a discussion concerning the definition(s) of the parameter PULSE DURATION as well as a description of the methods used in this work. The second is a description of the APMS system programs used to acquire and process the pulse source output waveform data. The third topic is a presentation of the results of tests conducted to evaluate the pulse distortion contributed by the twin-lead-to-SMA adapter used for the PIU measurement plane calibration. The fourth topic is a presentation of the calibration data along with an analysis of that data.

Attempting to define the parameters of an arbitrary pulse waveform is neither a simple nor a trivial task. Standards on the subject do exist, however [4-7], which go far towards resolving the many difficulties typically encountered. Figure 16, taken from [6] is a pictorial description of all of the parameters of a single pulse. As shown, there are eight different time parameters and six amplitude parameters. For this work, three of these parameters are of direct interest, namely, PULSE BASELINE, PULSE TOPLINE, and PULSE DURATION. That is to say, once the PULSE BASELINE (0 percent level) and PULSE TOPLINE (100 percent level) amplitudes of a pulse are known, the PULSE DURATION (time between mesial, or 50 percent points) may be calculated.

The major problem that arises in the practical measurement of PULSE DURATION is the definition and determination of the PULSE BASELINE and PULSE TOPLINE amplitudes. Actual measured pulses seldom exhibit perfectly flat baselines or toplines, so the person performing the measurement usually is forced to choose, perhaps arbitrarily, a method or algorithm for determining these two amplitudes. This arbitrariness often leads to different operators choosing different methods and consequently arriving at different estimates for the pulse parameters of the same pulse waveform. Clearly, then, accurate pulse parameter estimates require the use of techniques and definitions agreed upon by everyone performing these measurements. Although still relatively unknown and unused by persons in the electronic and measurement field, the pulse standards cited above resolve many of these difficulties.

Of the four algorithms for determining PULSE BASELINE and PULSE TOPLINE magnitudes defined in [5], two were chosen for use in this work. The first is the PEAK MAGNITUDE algorithm which consists simply of choosing the smallest and largest voltage values of the recorded waveform as the PULSE BASELINE and PULSE TOPLINE, respectively. The second algorithm chosen, the MODE OF DENSITY DISTRIBUTION, is a bit more complicated. Figure 17 (reproduced from [5]) illustrates the technique. As may be seen in (a), the recorded pulse waveform voltage-time plane is superimposed upon a grid of small Δm - Δt rectangles. Then, as shown in (b), a probability density histogram is constructed by counting the number of Δm - Δt rectangles through which the waveform passes for each incremental magnitude, Δm. The PULSE BASELINE and PULSE TOPLINE are then defined to be the lower and upper modes (or peaks) of this bimodal histogram, respectively.

Two FORTRAN programs were used to perform pulse waveform acquisition and analysis. The first is entitled GMEAS. This program is a generalized APMS waveform acquisition program that causes the APMS sampling oscilloscope to measure a 2^n-point (n an integer less than or equal to 11) sampled data waveform and store it as a FORTRAN array in the APMS minicomputer memory. This array is then corrected for scale factor errors by use of the previously obtained vertical and horizontal calibration factor files described in sections 4.3.1.2 and 4.3.1.3. Finally, this corrected pulse waveform array is written to a flexible disk file for further analysis by other programs.

GMEAS contains a number of run-time options and was designed to execute interactively. A typical terminal dialog listing is shown in figure 18. Referring to this listing the operator was first asked to type in the desired number of points for the pulse waveform acquisition (2048), the nominal voltage scale (100 mV/cm), and the nominal time scale (20 ns/cm). Next, the operator was asked if vertical and horizontal scale correction was desired. Since, in this case, the response was "yes," the names of the vertical and horizontal calibration factor disk files were requested. The next two questions allow the operator to correct an anomaly in the APMS sampling oscilloscope. Often, the first few points of an acquired waveform are incorrect due to serial correlation of the samples upon sweep retrace. When this error occurs, the operator is given the option of linearly correcting the values of these few points. In this example, the first five points were all reset to the mean of the values of points six through ten. The next question allows the operator the option of recording the no-signal baseline prior to recording the actual pulse waveform. Choosing this option accomplishes two things. First, it establishes the zero volt level on the screen, and secondly, by subtracting this recorded baseline, point-by-point, from the recorded waveform, baseline nonlinearity errors are removed from the recorded pulse waveform. Lastly, the operator is instructed to apply the pulse generator signal to the APMS sampling head, and, when ready, type a "1" to begin recording. Although not shown, the operator is then asked to select a disk file name for the acquired waveform. The program then writes the waveform data to disk along with the vertical and horizontal scale factors and the number of points in the waveform. Total execution time for this program is typically ten minutes.

The program used to analyze the pulse waveforms recorded with GMEAS, entitled PWA2KA, calculates all of the relevant pulse parameters using either the PEAK MAGNITUDE or the MODE OF DENSITY DISTRIBUTION definitions for PULSE TOPLINE and PULSE BASELINE described previously. In addition, it produces a graph on the CRT terminal screen of both the pulse waveform and its associated occurrence density histogram.

Figure 19 is a typical listing of the operator/program dialog and figures 20a and 20b are typical graphical/alphanumeric program outputs. Figures 20a and 20b are representations of the same pulse waveform data, the difference being that figure 20a was generated using the PEAK MAGNITUDE definition for the 0 percent and 100 percent levels while figure 20b was generated using the MODE OF DENSITY DISTRIBUTION definition. In the COMMENTS line of these figures, the words MIN-MAX refer to the PEAK MAGNITUDE definition and the word HISTOGRAM refers to the MODE OF DENSITY DISTRIBUTION definition.

Referring to figure 19, the operator was first asked for the number of waveforms to be analyzed (one) and the waveform data disk file name (T100). The program then lists 13 variables/parameters. In order, these are the number of data points found in the disk file (2048), the total time window (200 ns), the time spacing between samples (97.655 ps), the histogram limit (20), the value of the first data point (-2.375 mV), the value of the last data point (0.645 mV), the minimum value of all the data points (-4.133 mV), the maximum value of all the data points (390.925 mV), the value of the 0 percent level using the HISTOGRAM definition (-2.127 mV), the number of data points lying in the vertical interval corresponding to -2.127 mV (201 points), the value of the 100 percent level using the same definition (389.845 mV), the number of data points lying in this corresponding vertical interval (134 points), and, finally, the magnitude of the vertical expressed in millivolts (0.308639 mV) and in a percentage of the PULSE AMPLITUDE (0.078124 percent). The program then asks the operator if the histogram data is acceptable and, although not shown, then asks for the desired 0 percent and 100 percent definitions. It should be noted that the number of digits (in the above floating point numbers) are not all significant in terms of measurement accuracy.

In figure 20a, the MIN-MAX definition for the 0 percent and 100 percent levels was chosen, while in figure 20b the HISTOGRAM method was chosen. It is evident that there are small differences in all of the pulse parameter estimates in the two figures even though the pulse waveform data was the same. It may be noted in particular that the MIN-MAX PULSE DURATION was 100.321 ns representing a difference as a percentage of nominal value of approximately 0.01 percent. Consequently, it was concluded that this pulse was a "well-behaved" pulse suitable for use as a PULSE DURATION standard due to its relative insensitivity to the 0 percent and 100 percent level definitions used.

For purposes of evaluating the effects of the interface adapters used for the EQUATE station PIU tests, a 20 ns pulse from the source was used. Referring again to figure 15, it may be observed that the 3 mm SMA/twin lead adapter (closest to the sampling head) lies to the right of the measurement reference plane. Thus, the SMA/twin lead adapter must be considered part of the APMS measurement system, and it becomes necessary to show that the SMA/twin lead adapter contributes negligible distortion to the pulse waveform calibration measurements.

This step was accomplished by first calibrating the 20 ns pulse with the source connected to the sampling head via only the 6-ft length of RG-58C/U. Then, the calibration was repeated with the adapter inserted and the difference in the mean value of the parameter PULSE DURATION was observed. Figure 21 shows the recorded 20 ns pulse waveform directly into the sampler and figure 22 shows this same waveform after insertion of the adapter. It may be observed that there is no discernable difference in the two waveform shapes. Also, the calculated mean value of the measurements of the direct-to-sampler pulse waveform was 19.404 ns while that with the adapter inserted was 19.419 ns. This amounts to a difference of only 0.025 percent for the 20 ns pulse and, for the narrowest pulse used in the EQUATE stations tests, 50 ns, this deviation is only 0.01 percent. Therefore, with no visible distortion and such a small difference in PULSE DURATION, it was concluded that the effects of this adapter could be safely neglected.

Such was not the case, however, for pulse waveforms calibrated through the complete PIU test configuration. Figure 23 is a record of an unfiltered 20 ns pulse waveform measured through the PIU calibration configuration shown in figure 21. Comparison of this waveshape with that of a similar pulse presented directly to the sampler shown in figure 15 indicates an appreciable amount of distortion is caused by the BNC/twin lead adapter and the PIU connectors. Also, the comparison of mean PULSE DURATION gave values of 19.404 ns for the direct-to-sampler waveform and 19.380 ns for the PIU channel waveform. This is a 0.1 percent difference for the 20 ns pulse. Because the objective was to provide a known pulse waveform to the EQUATE station UUT measurement planes, this error, along with the observed distortion, was felt to be sufficient to require separate calibrations for each pulse source waveform, i.e., one for the DIU channel and one for the PIU channel.

The pulse source was calibrated for the parameter PULSE DURATION at nominal values of 50, 100, 200, 500, and 1000 ns for both DIU and PIU measurements. The time and voltage axes of the APMS were calibrated immediately prior to each pulse waveform measurement. Also, each waveform acquisition and analysis was performed three times in succession so that an estimated measurement standard deviation could be calculated and used to analyze measurement repeatability.

Figures 24a and b through 35a and b are the graphical/alphanumeric outputs from the pulse waveform analysis program, PWA2KA, for each of the pulse waveform calibrations. The (a) figures are based on the MIN-MAX definition for the 0 percent and 100 percent amplitude levels while the (b) figures are based on the HISTOGRAM definition for those levels. Those figures labeled "DIRECT TO SAMPLER" represent pulse waveforms measured at the DIU reference plane, and those labeled "THRU ITT CONNECTOR" represent those measured at the PIU reference plane.

Still referring to these waveform figures, the "+F" in the labels means that a Gaussian nine-pole filter was placed on the output of the pulse source. For the 50 and 100 ns pulses the filter employed had a nominal TRANSITION DURATION of 5 ns while that used for the 200, 500, and 1000 ns pulses had a nominal TRANSITION DURATION of 50 ns. The single exception to this use of filters is shown in figures 32 and 33 which are labeled "+FF." These 500 ns pulses were specially filtered by use of the 5 ns nine-pole filter in series with a 140 MHz sharp cutoff filter to produce pulse waveforms, as shown, with an appreciable amount of overshoot, undershoot, and ringing. These particular pulse waveshapes were created for purposes of testing the EQUATE station's ability to measure such distorted pulses accurately.

The pulse source was calibrated in April 1981 and again in June/July 1981. Tables 2 through 7 are summaries of the calibration data for each different nominal pulse duration (50, 100, 200, 500, special 500 ns, and 1000 ns.) Each table consists of 11 columns. Column 1 lists the date that the calibration was performed. Column 2, labeled "CNX," lists the calibration configuration with "BNC" representing the DIU configuration and "ITT," the PIU configuration. Column 3 lists the definitions used to estimate the 0 percent and 100 percent levels with "M-M" representing the MIN-MAX method and "HIST," the histogram method. The next column is labeled "FILTER" and lists the TRANSITION DURATION of the nine-pole filter used for that calibration. Columns 5 and 6 list the measured PULSE DURATION (T_d) and the estimated standard deviation σ, based on three complete measurements. Columns 7 and 8 list the PULSE AMPLITUDE (V_a) and the associated estimated standard deviation σ. Similarly, columns 9 and 10 list the measured PULSE BASELINE amplitude. Lastly, column 11 lists the change in PULSE DURATION calibration values between the April and June/July calibrations expressed as a percentage of nominal value.

5. FIELD TESTS AND PERFORMANCE VERIFICATION OF ATE SYSTEMS

5.1 Field Test of the EQUATE System at the Army Depot, Tobyhanna, PA

5.1.1 Test Procedures Used From DC to 10 MHz

The first application of the source to an EQUATE system was at the Tobyhanna Army Depot where two systems are used. Since both of these systems were in daily use, the generation and verification of the NBS test software and the taking of measurements was planned to be as least disruptive as possible. Three measurement programs were written in ATLAS to run on the EQUATE system to measure dc voltages, low frequency ac voltages in the range of 50 Hz to 50 kHz, and high frequency ac voltages in the frequency range of 60 kHz to 10 MHz. These programs were designated as DCV, ACVL, and ACVH, respectively, and were written with the assistance of Army programmers at Tobyhanna familiar with the EQUATE system. A listing of these three programs is given in appendix A.

The basic test procedures used with the EQUATE system were as follows: A preprogrammed tape of test voltages was prepared prior to the visit. After the on-site equipment had been operating for at least eight hours, the tape was loaded into the source. The voltage test signal from the source was applied to the programmable interface unit (PIU) connector through an adapter designed to apply the voltage to selected pairs of measurement pins. The pairs of measurement pins were randomly chosen to emulate a UUT that might be connected to the EQUATE system. Since the specifications for the EQUATE system made no reference to measurement errors associated with measurement pin assignment, it was presumed that various pin combinations would exhibit similar characteristics. In general, six pin-pairs were chosen for the measurements and, of these, four pairs were remeasured to determine if measurement errors were associated with specific pairs.

The source was interconnected to the EQUATE system as shown in figure 36. The software in all three ATLAS programs executed initial statements that selected the PIU as the input to the EQUATE system, stored the number associated with the pin-pairs to be measured (TPHI and TPLO), and stored the maximum number of voltage measurements to be made at each pin-pair (MAXSTP). In both the ac and dc measurement programs, as each voltage was applied to the EQUATE system, two voltage measurements were made using the MEASURE statement. The first MEASURE command caused a voltage measurement with the EQUATE system in the autoranging mode, and stored the result in the variable, VMAX. The second MEASURE command remeasured the same voltage (VDC or VAC), using the results of the first measurement to specify the maximum voltage to be measured. Thus, the proper range was found for making the actual voltage measurement that was printed and recorded on the EQUATE system disk file. In a similar manner the ac programs also measured and recorded the frequency of the input voltage and used that value as the maximum frequency for the final voltage measurement. Those familiar with the EQUATE system at Tobyhanna felt that this procedure was an effective way of assuring that the voltage range would be selected which provided the best system resolution and accuracy. At the end of the measurement cycle, a 5 V "test complete" pulse was sent from a designated set of pins on the PIU (127 and 128) to the source in order to signal the end of the voltage measurement. The source responded to this signal by providing the next voltage in the preprogrammed sequence. After a three-second delay, the next set of measurements was initiated, and the process continued until the required number of measurements was made. At this point, the operator intervened to either select another set of PIU pins or to terminate the program.

Part of the experimental design of the field test included the choice of voltage sequences that would be measured by the EQUATE systems. It was decided that the test voltages to be measured should be a random sequence of amplitudes and frequencies in order to emulate the testing of a UUT whose output could assume a wide range of values. As originally designed, the voltage sequence covered the range of ±0.1 V dc through ±200 V dc and from 0.1 V ac (rms) through a maximum of 140 V ac (400 V ac peak-to-peak). This range was chosen to be within the specifications of the EQUATE system measurement capability. The final sequence used in the tests is given in tables 8A and 8B.

Although a randomized measurement sequence was desirable from the theoretical point of view, this procedure was difficult to implement in the first field tests. The relatively short time that was available in which to write and debug the ATLAS field test software, interface the calibrator to the EQUATE system, and take final measurements on an unfamiliar system were extenuating factors. Three problems were thus presented with attempting this randomized approach. First, it was found on initial testing that the EQUATE sytem would sometimes interpret a voltage to be slightly higher than the maximum of ±200 V dc, or 140 V ac, simply due to measurement errors. This effect would cause the system to abort the ATLAS program and return to the Command Language Interpreter (CLI) mode of operation. At that point, partial files would have to be closed and deleted, and the program restarted. In addition, there was some concern about the advisability of applying voltages to the input of the EQUATE system that approached its specified limits since failures in input components had been known to result from this practice. The source program tape was modified therefore to remove the three +200 V dc and the three -200 V dc commands. However, in order to obtain some data near the operating limits of the EQUATE system, one +195 and one -195 V dc command were included at the end of the test sequence. The ac tape was also edited to remove the five measurements at 140 V ac. Additionally, it was found during the execution of the ACVL program that the low input impedance of the PIU caused the rated current capability of the source (6 mA) to be exceeded at 70 V ac and 20 kHz. This data point was also removed from the program tape.

A second problem occurred because of two errors in programming the data on the dc and low frequency ac tapes. Both the +0.1 and -0.1 V dc data points were to be replicated three times. An error in randomizing the data caused the +0.1 point to be replicated twice, while the -0.1 V dc point was repeated four times. In addition, the 0.7 V ac, 100 Hz data point was repeated inadvertently in the low frequency sequence.

The third problem encountered was in obtaining the high frequency ac data. To appreciate this problem, it is necessary to understand the voltage measurement system internal to the EQUATE system. The measurement system consists of two sampling units: the low-speed voltage sampling unit (LSVSU) and the high-speed voltage sampling unit (HSVSU). To measure dc or ac voltages below 50 kHz, the LSVSU must be used. Above 50 kHz, the HSVSU is required. The input to the LSVSU is normally a pin-pair or differential type connection, while the input to the HSVSU is a single pin and ground (single ended) connection. In order to measure an ac voltage that varies over a wide frequency range, as originally planned for the high frequency, wide-band output of the calibrator, a change in the connections would have to be accomplished. In addition, the wide-band output of the calibrator must be terminated into a 50 Ω load for its amplitude to be correct. The EQUATE system software manual gives the operator the choice of making either "buffered" or "unbuffered" measurements while using the HSVSU. Furthermore, two notes in the programming manual state that (1) the "TEST-EQUIP-IMP" of 50 Ω is available only above 50 kHz, and (2) that the user is not to use the TEST-EQUIP-IMP field of an ATLAS statement with a buffered measurement or with the RF-probe. On this basis it was decided to make the measurements in the unbuffered mode using the internal 50 Ω load. We were also told that this procedure would exercise the measurement capability of the EQUATE system as it is commonly used in testing UUTs. However, applying high frequency signals directly to the analog bus, without using a buffer amplifier, resulted in excessive loading of the calibrator. As a result, the voltages measured at the Army Depot were excessively low and out of tolerence. Hence, information was not obtained on the accuracy of a properly buffered and terminated measurement channel in the frequency range of 60 kHz to 10 MHz.

5.1.2 Test Procedure Used With Pulse Source

Along with the dc and low frequency tests described above, one of the EQUATE systems (serial #5) was tested for its ability to measure the parameter PULSE DURATION over a range of 50 to 1000 ns. Briefly, this was accomplished by programming the EQUATE station to measure the PULSE DURATION parameter of a variety of pulses generated by the NBS calibrated pulse source described in chapter 4.

The EQUATE system hardware is made up of a minicomputer system with peripherals, signal stimulus electronics, signal measurement electronics, and all necessary switching and connector components. The system may be used in either the direct interface unit mode (DIU) or programmable interface unit mode (PIU). Pulse measurement tests were conducted in both modes; the main differences between the modes from the operator's viewpoint are involved with the different measurement port connectors required. The PIU measurement port is a multipin zero-insertion-force (ZIF) connector with 128 signal pins that may be programmed to be either signal source pins or signal measurement pins. In addition, there are 128 signal pins which are programmable only as signal measurement pins. The DIU measurement port for pulse parameter measurements consists of six BNC connectors.

According to the EQUATE system specifications [8], the parameter PULSE DURATION may be measured over a range of from 20 ns to 60 s (50 ns minimum detectable pulse). The pulse threshold amplitude range is from ±50 mV to ±200 V peak. The accuracy specification is ±(5 ns + trigger error) where the trigger error is defined as

$$\text{T.E.} < \pm \frac{3.2 \times 10^{-3}}{N} \times \frac{\text{sensitivity}}{\text{signal amplitude}} ,$$

where N = number of cycles of input signal over which the measurement took place. Also pertinent is the system specification that the PIU may be used for signal frequencies from dc to 10 MHz, and the DIU for signal frequencies from dc to 500 MHz [9].

The NBS pulse source was used to test the EQUATE station's ability to measure PULSE DURATION through both the PIU and DIU measurement ports. For each of these ports, pulse source pulses with a nominal PULSE AMPLITUDE of 400 mV and a pulse repetition rate of 200 KHz were used. As mentioned in chapter 4, nominal PULSE DURATIONS of 50, 100, 200, 500, and 1000 ns were generated by the pulse source for measurement by the EQUATE station through the calibrated UUT output interfaces for both the PIU and DIU connectors.

On the EQUATE system, the measurement of the parameter PULSE DURATION is a three-step process. First the value of the 100 percent voltage level of the pulse is measured (VOLTAGE-P-MAX). Then, the value of the 0 percent voltage level is measured (VOLTAGE-P-MIN). Finally, a time interval measurement is conducted between the computed 50 percent level positive slope portion of the pulse and the computed 50 percent level negative slope portion. This latter measurement yields the value of the PULSE DURATION.

At the Army Depot, in the interest of saving time, existing EQUATE ATLAS programs written previously by site personnel were modified and used for these tests. Although the complete source text of these programs is too lengthy to reproduce in this report, the three key ATLAS instructions used to perform these tests are reproduced and described below.

For the PIU tests the first ATLAS instruction was:

```
MONITOR (VOLTAGE-P-MAX 'VMAX' V),
PULSED-DC, VOLTAGE-P MAX 'VM' V,
PERIOD 'P' USEC, DUTY-CYCLE 'DC' PC,
TEST-EQUIP-IMP 50 OHM, CNX HI 'MHITP'$.
```

This instruction causes the value of the 100 percent voltage level of the pulse applied to the PIU test point 'MHITP' to be measured, recorded into memory, and displayed on the monitor screen. The instruction contains four input variable arguments and one output variable argument. The four input variables are the expected value of the maximum pulse amplitude, 'VM,' the pulse repetition period, 'P,' the percent pulse duty cycle, 'PC,' and the PIU test pin to which the pulse is applied, 'MHITP.' The output variable, 'VMAX,' contains the measurement answer upon execution of the program statement.

As discerned from the manufacturer's EQUATE programming manual, the ATLAS compiler causes the pulse 100 percent voltage level measurement to be accomplished in the following manner. First, the pin number selected by the variable 'MHITP' causes the necessary switching to connect that PIU pin to the measurement bus and to either a low-speed or a high-speed voltage sampler. The value that is input to the period variable, 'P,' determines which sampler is selected; if the period is less than 10 kHz the low-speed sampler is selected, and if the period is greater than 10 kHz the high-speed sampler is connected to the measurement bus. The amplitude input variable, 'VM,' causes an appropriate amount of gain or attenuation to be switched into the measurement channel to ensure that a suitable pulse signal level is seen by the sampler. The remaining input variable, 'PC,' the pulse duty cycle, or percent of time that the pulse is on with respect to the pulse repetition period determines the number of voltage sample measurements taken by the sampler.

Once all of the bus switching, gain setting, etc., has taken place, the sampler is instructed to sample the pulse waveform, randomly in time, between 1000 and 100,000 times depending on the duty cycle variable, 'PC.' Smaller values of pulse duty cycle cause more samples to be taken. Of these thousands of voltage samples taken, the 65 samples of largest voltage level are retained in memory. Of these 65, the smallest ten values are averaged and this mean value is the answer returned to the variable 'VMAX' and displayed on the monitor screen as the pulse voltage peak maximum or 100 percent voltage level.

The ATLAS instruction used next to determine the pulse voltage baseline, or 0 percent voltage level was:

```
MONITOR (VOLTAGE-P-MIN 'V'), PULSED-DC,
VOLTAGE-P MIN 'VMIN' V, PERIOD 'P' USEC,
DUTY-CYCLE 'DC' PC, TEST-EQUIP-IMP 50 OHM,
CNX HI 'MHITP'$.
```

This instruction is almost identical to the VOLTAGE-P-MAX instruction and causes the hardware to behave in exactly the same manner. The only difference is in the behavior of the random sampling algorithm. In this case the 65 samples of smallest voltage level are retained in memory, and of these 65, the largest ten values are averaged. This mean value is then returned to the variable 'VMIN' and displayed on the screen.

Once the values of the pulse 100 percent and 0 percent voltage levels have been measured and recorded, the ATLAS program instructs the computer to calculate the 50 percent voltage level, i.e., ('VMAX' + 'VMIN')/2. This 50 percent level is then recorded into the variable 'THRESHOLD' for use in the time interval measurement instruction. This third key instruction, which actually measures the pulse parameter PULSE DURATION, is written in ATLAS as:

```
MONITOR (TIME 'PDPN' USEC), TIME-INTERVAL,
SINGLE-CHANNEL, MAX-TIME 1 SEC, START,
VOLTAGE-P MAX 'VMAX' V, THRESHOLD 'THRESHOLD' V,
POS-SLOPE, TEST-EQUIP-IMP 50 OHM, CNX
HI 'MHITP', STOP, THRESHOLD 'THRESHOLD' V,
NEG-SLOPE$.
```

Again, as discerned from the manufacturer's EQUATE programming manual, the execution of this instruction causes the signal present at PIU test point 'MHITP' to be routed via the measurement bus to an integral high-speed timer/counter called the frequency sampling unit (FSU). The arguments of this instruction tell the FSU to begin counting a 500 MHz internal clock when the incoming signal exceeds the voltage value contained in the variable 'THRESHOLD' with a positive slope and to stop counting the clock when the signal voltage drops down below 'THRESHOLD' volts with a negative slope. The amount of elapsed time measured by the counter is recorded as the PULSE DURATION into the variable 'PDPN' and is displayed on the monitor screen. It should be noted that the use of a 500 MHz clock in this measurement technique limits the PULSE DURATION measurement resolution to 2 ns $(500\ \text{MHz})^{-1}$.

For all of the EQUATE PIU measurements, the low side of the NBS pulse source was connected to a different PIU signal pin and grounded within the EQUATE system with the ATLAS instruction:

```
CONNECT EARTH, CNX TP 'MLOTP'$.
```

This method of grounding is only used in the PIU unbuffered mode.

The pulse tests were also conducted through the EQUATE DIU UUT measurement port. The three key ATLAS instructions used to perform these measurements are:

```
MONITOR (VOLTAGE-P-MAX 'VMAX' V), PULSED-DC,
VOLTAGE-P MAX 'VM' V, PERIOD 'P' USEC,
DUTY-CYCLE 'DC' PC, TEST-EQUIP-IMP 50 OHM,
CNX BNC 'MHITP'$,

MONITOR (VOLTAGE-P-MIN 'V'), PULSED-DC,
VOLTAGE-P MIN 'VMIN' V, PERIOD 'P' USEC,
DUTY-CYCLE 'DC' PC, TEST-EQUIP-IMP 50 OHM,
CNX BNC 'MHITP'$,
```

and

```
MONITOR (TIME 'PDPN" USEC), TIME-INTERVAL,
SINGLE-CHANNEL, MAX-TIME 1 SEC, START,
VOLTAGE-P MAX 'VMAX' V, THRESHOLD 'THRESHOLD' V,
POS-SLOPE, TEST-EQUIP-IMP 50 OHM, CNX BNC
'MHITP', STOP, THRESHOLD 'THRESHOLD' V,
NEG-SLOPE$.
```

With the exception of the change in measurement ports from the PIU ZIF connector to the DIU BNC connector, these instructions are virtually identical to those used for the PIU tests.

Although not included in the project work statement, an attempt was made to program the EQUATE station to measure the parameter PULSE TRANSITION DURATION (10 to 90 percent). This was accomplished by instructing the computer to calculate the 10 percent and 90 percent voltage levels of the measured pulse and placing these values into the variables "TEN" and "NINE," respectively. Then, the following ATLAS time interval measurement instruction was executed:

```
MONITOR (TIME 'TR' USEC) TIME-INTERVAL,
SINGLE-CHANNEL, MAX-TIME 1 SEC, START,
VOLTAGE-P MAX 'VMAX' V, THRESHOLD 'TEN' V,
POS-SLOPE, TEST-EQUIP-IMP 50 OHM, CNX HI
'MHITP', STOP, THRESHOLD  'NINE' V, POS-SLOPE$.
```

This instruction should have measured the 10 to 90 percent first PULSE TRANSITION DURATION parameter and returned its value to the variable 'TR.' However, for reasons still undetermined, the system returned the message "NO MEASUREMENT COMPLETE" to the system terminal for all attempted measurements.

5.2 Test Data Collection and Analysis, Army

5.2.1 DC Signals

During each field test, the measurement data were printed on a hard copy printout on the system line printer as well as written into a disk file. The data on the disk file were then transferred to a magnetic tape via the CLI XFER command. In this manner the measurements were stored in machine-readable form for later data analysis. Additionally, hard copy and magnetic tape outputs were made of the ATLAS programs that were used to acquire the data. At NBS the magnetic tape was read, and the data on the tape were checked against the hard copy output from the EQUATE station. Since the tape formats of the NBS computer are slightly different than those written by the EQUATE station, some data editing was necessary. The recorded measurements were then compared to the preprogrammed values that were applied from the calibrator and the deviations were calculated. The dc measurements consisted of 440 data points, representing 44 voltages presented to each of the six PIU pin-pairs with four pin-pairs replicated. A sample printout of the data after the aforementioned reduction is shown in table 9.

The distribution of the number of data points within a given tolerance band is shown in the histogram, figure 37. It should be appreciated that the data shown in this figure are a summary description of the population of measurements made on this EQUATE station for all dc voltages at all pin-pairs. The distribution of errors as a function of applied voltage may be seen in the next two figures. Figure 38 shows the deviation from nominal, as a function of voltage, over the entire voltage range investigated, -195 to +195 V dc. It is clear that most of the deviations from nominal occur near zero volts. Figure 39 shows an expansion of the scale of figure 38 from -5 V dc to +5 V dc. Notice that at progressively lower voltages, the negative voltages tend to have negative deviations and the positive voltages tend to have positive deviations.

Using the acquired data, the pin-to-pin (or channel-to-channel) reproducibility may also be analyzed. Since, in general, a given set of pins were tested at a given voltage level three times, the reproducibility of the measurements may be plotted as shown in figures 40a to 40c. Figure 40a shows the set of measurements made at +100 V dc at the six pin-pairs along with the four replications. The pin-to-pin reproducibility of measurements is not necessarily simply grouped by pin set as implied in the data of figures 40a through 40c. A similar plot of the pin-to-pin reproducibility for -100 V dc shows that 5 out of 30 measurements have a positive error, while the remaining 25 have a negative error from 0.075 to 0.10 percent. When -5 V dc was applied to the EQUATE system, the pin-to-pin reproducibility at pin set number 3 (corresponding to pin numbers 71 and 72) yielded an outlying set of measurements. The pin-to-pin reproducibility for applied voltages of -100 and -5 V dc are shown in the plots 40b and 40c, respectively.

From the preceding plots, it is construed that this pin-pair (71-72) might be one of the more consistent of those investigated. One possible cause of the lack of pin-to-pin reproducibility could be variations in the contact resistance of relays in the PIU network. It is well known that relay contacts which are switched "dry," or at very low contact current are susceptible to large contact resistance variations. No effort was made to actually verify that this was actually the case, however.

5.2.2 AC Signals to 50 kHz

The ac data taken on the Army EQUATE system represents 464 measurements made at six pin-pairs with two pin-pairs replicated. A sample printout of the ac data after reduction is shown in table 10. The applied voltages covered the range of 0.3 to 70 V ac and frequencies from 50 Hz to 50 kHz. One data point, at observation number 390, was in error; the EQUATE system measured an approximate 60 mV ac signal when a 70 V ac, 100 Hz signal was applied. It is apparent that this data point is grossly in error and represents a test malfunction rather than a timely measurement error. One criterion simply used to distinguish machine malfunctions from measurement errors is to determine if a skilled operator of the measurement system would be misled by such outlying data. In our estimation, a skilled operator would be suspicious of this point, justifying its exclusion from further data analysis.

The same data is shown as a histogram in figure 41. It is evident from the bimodal distribution that some process caused an abrupt change in the deviations. Plotting the deviations against the applied voltage, as shown in figure 42, shows the cause for the bimodal distribution. Of the 463 ac voltage measurements acquired, 248 were within the voltage range of 0.3 to 3.0 V ac. Of these 248 measurements, 244 were within a tolerance of ±1 percent. However, between 7 and 70 V ac, 215 measurements were acquired and 181 were within the range of -1 to -3 percent. Thus, there appears to be a systematic error that affected the voltage measurements within the 7 to 70 V ac range. This result is typical of what would be expected from a multi-range voltmeter that had an error in its range attenuators. Those points scattered around the two major clusters of data points in figure 42 all represent measurements at a frequency of

50 kHz. This observation is clearly seen if the deviation from nominal is plotted against frequency, as shown in figure 43. In addition to the bimodal distribution of the voltage distribution, it is also seen that the greatest spread in errors is at the highest frequency. It is suspected that errors that are as strongly dependent on frequency as exhibited in this figure are caused by an effect of the sampling process that is used in the EQUATE system to measure ac voltages.

5.2.3 Pulses

The NBS pulse source was used to test the Tobyhanna EQUATE station (serial #5) on three different PIU pin-pairs (HI-PIN 1, LO-PIN 11, HI-PIN 44, LO-PIN 28 and HI-PIN 120, LO-PIN 92) and three different DIU BNC connectors (numbers 1, 2, and 4). For each of these measurement port pins/connectors the EQUATE station was instructed to make five complete sequential PULSE DURATION measurements on each of the nominal pulse source calibrated pulses, i.e., 50, 100, 200, 500, 500 (sharp-cutoff filter), and 1000 ns. As previously mentioned, the nominal pulse source pulse amplitudes were 400 mV and the nominal pulse repetition frequency was 200 kHz in all cases.

The EQUATE measured data is summarized in tables 11 through 16. Each table represents the measurement results for all pulses measured on a particular PIU pin or DIU connector. Each table is arranged in the following manner: Column 1, labeled "NBS Pulse Duration" lists the NBS calibration value (MIN-MAX definition) for each of the six different pulses tested. Column 2, labeled "τ_D," lists the five sequential measured values obtained from the EQUATE station for the pulse parameter obtained PULSE DURATION for each of the six different pulses. Column 3, labeled "τ_D" lists the mean value of each of the sets of five values in column 2, and column 4, labeled "σ," lists the standard deviation of each of those sets. Columns 5, 6, and 7 list the five individual voltage peak maxima (100 percent voltage level) recorded for each measurement along with their means and standard deviations, respectively, while columns 8, 9, and 10 contain the same corresponding measurement data for the voltage peak minima (0 percent voltage level). Column 11, labeled "$\Delta\tau$ (ns)," lists the difference between the NBS pulse source calibrated values for PULSE DURATION of column 1 and the EQUATE measured mean value of column 3 in ns. These data are in the column 11 rows labeled "MEAN." Column 11 also lists the difference between the pulse source calibrated value and the worst individual EQUATE measured value (largest absolute difference). These data are labeled "WC," or worst case. Column 12 contains the same information listed in column 11, but the deviations are listed as a percentage deviation from nominal rather than in ns.

A number of observations may be drawn from these data. First, the EQUATE measurements of PULSE DURATION vary considerably, with deviations from nominal ranging from -16.1 percent to less than 1 percent. Generally, the larger errors occur for measurement of faster pulses. Also, particularly in the case of the PIU measurements, the measured values of voltage peak maxima (column 5) deviate considerably from the nominal value of 400 mV. In addition, these values appear to increase monotonically with nominal pulse duration.

5.3 Field Test of the EQUATE System at the Naval Avionics Center, Indianapolis, IN

5.3.1 Test Procedure Used From DC to 10 MHz

The second application of the source to an EQUATE system was at the Naval Avionics Facility. Prior to our visit to the Naval Avionics Facility, the ATLAS programs that were used at Tobyhanna Army Depot were sent to the Naval Avionics Facility for inspection and comment. Some modifications were made to ensure software compatibility to the Navy EQUATE system. In general, the same basic procedure was used at the Naval Avionics Facility as was used at Tobyhanna Army Depot. The three programs used to measure dc voltage and low- and high-frequency ac voltages were reentered at the Navy site since the program tape prepared at Tobyhanna Army Depot could not be read directly on the Navy EQUATE system. The ATLAS programs used at the Naval Avionics Facility are listed in appendix B. It was planned to interconnect the source in the same manner as was previously done at Tobyhanna Army Depot. However, immediately before our visit, it was learned that the front-panel connectors on the Navy EQUATE system differed from those used by the Army at Tobyhanna Army Depot. The cable from the calibrator was connected to the PIU in this case by a transition fixture provided by the Naval Avionics Facility for this purpose. The fixture consisted of an array of banana jacks mounted on the rear of a multipin connector which mated with the PIU.

Several minor modifications were made to the sequence of voltages that were applied to the Navy EQUATE system. The highest dc voltage applied was ±195 V, and this voltage was replaced in the original sequence such that both the positive and negative voltage appears three times.

During the test of the EQUATE system at the Naval Avionics Facility, the system placed excessive loading on the calibrator at the 70 V ac and 20 kHz point. This overloading was the same problem encountered previously at Tobyhanna Army Depot, and the action taken was also the same, namely, to remove this data point from the sequence. The final sequence of ac and dc voltages applied to the EQUATE system is shown in table 17.

The particular EQUATE system at the Naval Avionics Facility used a computing counter to acquire the frequency of the ac signal to be measured. Two difficulties were encountered with this unit. First, the counter could not properly acquire a frequency when the voltage range of the counter was set on the 300 V ac scale. This scale was used to measure the frequencies of all 130 V ac signals. Secondly, the trigger level of the counter exhibited a hysteresis of approximately 100 mV. This phenomenon resulted in erratic frequency measurements for signals at or below this voltage level.

5.3.2 Test Procedure Used With Pulse Source

The NBS pulse source pulses measured on the NAC EQUATE station were the same as those tested at Tobyhanna with the single exception that their nominal amplitudes were increased from 400 mV to 2.50 V. This proved to be necessary due to the fact that the timer/counter in the NAC EQUATE was not the same model as that in the Tobyhanna EQUATE and had different signal sensitivity requirements.

Also, the tests were expanded and modified somewhat, partially on the advice of NAC site personnel. In particular, the parameter PULSE DURATION was measured through the PIU both with and without an internal buffer amplifier connected into the measurement channel. Pulse TRANSITION DURATION (10 to 90 percent) measurements were also attempted at NAC with generally poor results, and no results were obtained in an attempt to use the EQUATE in a waveform recorder mode. Lastly, some time domain reflectometry (TDR) tests were conducted on the PIU and DIU measurement ports to aid in evaluating the measurement port impedances.

The PULSE DURATION measurements conducted on the Naval Avionics Facility EQUATE system were similar to those conducted on the Tobyhanna system. However, there were some differences which are listed below.

(a) The PIU multipin ZIF connector on the NAC EQUATE was physically different enough to preclude using the NBS interface adapter described in chapter 4. Therefore, the 3 mm SMA/twin lead adapter, also described in chapter 4, was used to interconnect the NBS pulse source and the PIU.

(b) At Tobyhanna, the NBS pulse source high and low terminals were each connected to PIU signal pins, i.e., HI-Pin #1, LO-PIN #11. The low pin was then grounded in the PIU with the ATLAS CONNECT EARTH instruction. At Indianapolis, the NBS pulse source high and low terminals were connected to a single signal pin and its shield pin, respectively, i.e., HI-PIN #1, LO-PIN #1S.

(c) PIU measurements of PULSE DURATION at Tobyhanna were performed only in the unbuffered mode while both buffered and unbuffered PIU measurements were performed at Indianapolis.

(d) The NBS pulse source nominal pulse amplitude used at Tobyhanna was 400 mV while that used at Indianapolis was 2.50 V. As mentioned, changing the amplitude was necessary to meet the sensitivity requirements of the two different timer/counters. This change did not affect the calibration of the NBS pulse source.

New ATLAS programs were written at Indianapolis to perform the pulse measurements. The ATLAS source program listing for the PIU pulse measurement is shown in appendix C. The only salient difference not already mentioned between the Tobyhanna ATLAS instructions and those used at Indianapolis is the replacement of the unit USEC with the unit NSEC in the time interval measurement instruction. A typical measurement output listing is shown in appendix D.

The program used to perform the DIU pulse measurements is shown in appendix E and a typical measurement output listing is given in appendix F. There was only one DIU BNC measurement connector on the Indianapolis EQUATE, as opposed to six on the Tobyhanna EQUATE, so only one measurement was conducted.

5.4 Test Data Collection and Analysis, Navy

5.4.1 DC Signals

Since the manner in which the data were acquired at the Naval Avionics Facility was similar to that described in the previous section, the presentation of the data is also similar. There were 480 dc voltage measurements taken on the EQUATE system at the Naval Avionics Facility. The 480 measurements represent a sequence of 48 voltages that were applied to each of six pin-pairs with four pin-pairs replicated. A typical printout of the data, after reduction, is shown in table 18. These data show that 60 of the 480 dc voltage measurements were in error by more than 50 percent. These errors seem to have two origins. The first and most obvious are sign reversal errors that occurred each time +100 V dc was applied to the system. Notice that since the system measured -100 V dc, a sign-reversal error causes a -200 percent error on the plot. The second source of error was a more random type which caused +10 V dc inputs to give erratic readings. The distribution of all dc observations is shown in figure 44, and the two types of errors may be clearly seen as distinct groupings in the distribution. The errors associated with the sign reversals are located at -200 percent, and those associated with the erroneous +10 V dc readings are grouped between -100 and -175 percent. The presence of these large errors was detected at NBS during the reduction of the data. Attempts were made to replicate a condition whereby the calibrator may have malfunctioned. The tape cassette used to program the calibrator was used in another calibrator to assure that it contained the expected data. The sign reversal errors could not be duplicated in the laboratory. It was later learned that the subject EQUATE system contained a defective analog-to-digital converter which malfunctioned only near full scale of the conversion range.

If the 60 data points that are in error by more than 50 percent are removed from further analysis, most of the errors are within a 2 percent band from +0.5 to -1.5 percent. The distribution of these points is shown in the histogram of figure 45. Figure 46 shows the percent error as a function of applied voltage over a range of -195 to +195 V dc. It is apparent that most of the deviations from nominal occurred near zero volts, similar to previously observed results on the EQUATE system at Tobyhanna Army Depot. Figure 47 shows the deviation from nominal over a voltage range of -5 to +5 V dc.

The ability of the EQUATE system to measure the same voltage at different PIU pin-pairs was investigated in the same manner as before. The pin-to-pin reproducibility for three dc voltage levels is shown in figures 48 through 50. Although there are slight deviations from nominal value at -100 V dc (approximately 0.6 percent), the ability of the system to measure the same voltage at various pin-pairs is quite uniform. Each plot in figures 48 through 50 represents data taken on each of six pin-pairs with replications of four pin-pairs.

5.4.2 AC Signals to 10 MHz

The performance of the Navy EQUATE system to acquire ac voltages was performed in nearly an identical manner as was performed with the Army system. A sequence of 448 ac observations was made between 50 Hz and 50 kHz and voltages 0.3 to 130 V ac. These voltages were applied to each of five pin-pairs on the DIU, and the measurements of two pin-pairs was replicated. The gross errors occurred at the seven data points corresponding to 7 V ac and 50 kHz. Since these points read consistently in error by more than 50 percent, they have been removed from further analysis. The distribution of these observations is shown in the histogram of figure 51. Notice that all the data points are within a ±1 percent tolerence except for some additional measurements made at 50 kHz. Figures 52 and 53 show the deviations from nominal plotted versus applied voltage and frequency, respectively. Figure 52, unlike figure 42, does not show a range error at 7 V ac. However, figure 53 does show that the errors are predominantly located at the 20 and 50 kHz measurements. This result is consistent with the observations shown in figure 43. A typical printout of the data, after reduction, is shown in table 19.

The ability of the EQUATE system to measure ac voltages between 0.6 and 10 MHz was also investigated on the Navy's EQUATE system. Since time was short, measurements were made at one input pin and one voltage to the DIU. To increase confidence in our measurements, the voltage applied to the EQUATE system was monitored by a 3 1/2 digit wide-band digital voltmeter obtained from the local Navy calibration laboratory. Figure 54 shows the deviations from the nominal as measured by both the digital meter and the EQUATE system. Since the output of the source is 50 Ω, the measured voltage is dependent on load impedance. An impedance mismatch of approximately 4 percent could account for the difference between the nominal value of 0.707 V ac and the value measured by the digital voltmeter. The differences in reading between the digital voltmeter and the EQUATE system, however, are not caused by mismatch between source and load impedances.

5.4.3 Pulses

The NBS PULSE DURATION pulse source was used to test the Indianapolis EQUATE station (serial #1) on three different PIU signal pin-shield pin-pairs (HI-PIN 1, LO-PIN-1S, HI-PIN 19, LO-PIN 19S and HI-PIN 58, LO-PIN 58S) and on the single available DIU BNC connector. As at Tobyhanna, the station was instructed to make five complete sequential PULSE DURATION measurements on each of the nominal pulse source calibrated pulses, i.e., 50, 100, 200, 500, and 1000 ns. The 500 ns sharp-cutoff pulse was not measured at Indianapolis due to time limitations. The nominal pulse source pulse amplitudes were 2.50 V, and the nominal pulse repetition frequency was 100 KHz in all cases.

The Indianapolis EQUATE measured data is summarized in tables 20 through 27. Tables 20, 22, and 24 represent the PIU unbuffered data, while tables 21, 23, and 25 represent the buffered data. Table 26 contains the DIU measurement data and table 27 contains data taken on the DIU to test the effects of varying the DUTY CYCLE value in the voltage peak MAX/MIN instructions. The arrangement of these tables is identical to that used for the Tobyhanna data (tables 11 through 16).

Somewhat similar to the Tobyhanna measured data, the Indianapolis data varied rather erratically, with percent deviations from nominal ranging between 15.5 percent and less than 1 percent. Also, similar to Tobyhanna was the fact that the unbuffered voltage peak maxima again exhibited a monotonic increase with nominal pulse duration increases. This trend was not observed in the buffered case, however.

In general, the buffered PIU measurement data appeared to be in closer agreement with the NBS nominal values than the unbuffered PIU data. Also, the single set of DIU measurement data taken at Indianapolis was in the best agreement of all with a maximum deviation of only 5.1 percent.

The results of the PIU and DIU time domain reflectometry (TDR) tests are shown in figures 55 through 57. Figure 55 shows the 50 Ω TDR signature looking into the single available DIU BNC connector. Ideally, if the channel exhibited a perfect wide-band 50 Ω impedance match, then the signature would appear as a smooth, uniformly flat-topped step waveform. The small deviations from flatness observed in the second and third time divisions are due to the TDR test pulse used and not the EQUATE system. The wiggles in the seventh and eighth time divisions, however, are caused by the EQUATE DIU channel and indicate small (a few ohms) mismatches in impedance.

Figures 56 and 57 are the TDR signatures of pin-pairs 1 and 1S of the PIU channel in the unbuffered and buffered modes, respectively. In this case the impedance deviations are much more significant than in the DIU case. As a function of distance starting from the PIU ZIF connector and looking into the PIU channel, the impedance first rises to about 100 Ω (positive peak at the beginning of time division four), drops to about 25 Ω, and then meanders erratically back to about 50 Ω in the ninth time division. The buffered and unbuffered TDR signatures differ noticeably only in time divisions six through nine. These large deviations of impedance are strong indications that pulses in the nanosecond domain measured through the PIU are appreciably distorted.

It was learned from Indianapolis site personnel that an ATLAS instruction exists that causes the EQUATE station to measure and record a pulse waveform in its entirety and store this sampled data waveform replica into the computer memory as a time series vector. A brief attempt was made to exercise this system feature, but, for unknown reasons, no meaningful results were obtained.

6. RECOMMENDATIONS FOR FUTURE EFFORTS

This report describes a limited experimental investigation of the measurement performance of two ATE stations (AN/USM-410 EQUATE). From the experience of preparing transport standards, collecting the test data, participating in various ATE-related meetings and conferences, perusal of pertinent literature, other on-site visits, etc., recommendations concerning future efforts are contained in the sections that follow.

6.1 Feasibility of Using Dynamic Transport Standards

The concept of performing an on-site, "in-situ," test of the system performance characteristics at the stimulus/measurement interface connector, using well-calibrated transport standards, has been demonstrated to have merit. Measurement uncertainties that would otherwise be undetermined can be quantified. An independent verification of the accuracy specification for basic dc and ac voltage and pulse duration measurements, common to most ATE system capability, can be established. The accuracy of other measurement (and stimulus) parameters is also capable of being verified in similar fashion. The in-situ, system test/calibration procedure accounts for hidden errors due to signal path losses, noise interference from pickup and cross-talk, and drifts or offsets in the electronics of the ATE. More subtle deleterious effects due to special algorithms used in the computer software or transmission/decoding errors in the digital interfaces of the system are also reflected in the data obtained from system performance verification/calibration testing. Section 5 in this report describes in detail the measured deviations from the nominal NBS value of the dc/ac voltage and pulse duration data on specified channels of the two AN/USM-410 systems studied. These systems utilize built-in secondary standards for dc and ac voltage as well as for frequency (time base). Self-check and calibration software (SYSCAL) is also provided for these systems. Nevertheless, significant deviations, both in magnitude and number of data points, were obtained from these two systems. Consequently, the feasibility of the dynamic transport standard concept for performance checking and system calibration purposes has been verified within the limitations mentioned.

6.1.1 Characteristics Desired

The stimulus sources for dc and ac voltage and for pulse duration, used as transport standards as described in this report, have served their purpose very well. However, as contrasted with present-day working standards and test instruments used as transport standards, the attributes of future dynamic transport standards (DTS) are anticipated to be the following [10]:

(a) Designed to provide multi-parameter and multi-level stimulus and measurement values, with a limited set of calibration reference points which are independently monitored under statistical control.

(b) Designed to calibrate ATE on a dynamic as well as on a static basis (ATE to be exercised at its operating speed; steady-state and transient parameters of the signals to be considered).

(c) Designed to interface mechanically and electrically to standard multipin connectors and adapters utilized for automatic testing purposes.

(d) Characterized and able to function over relatively wide environmental and operating conditions, including the presence of electromagnetic interference. Transportable and usable in working environments of ATE.

(e) Designed to contain built-in microcomputers for data logging, for remote programmability via standard buses (e.g., IEEE-488), and for digital processing of data and control signals of the stimulus and measurement hardware.

(f) Designed for rapid calibration against higher echelon standards and to contain extensive self-diagnostic means.

Some of these attributes can be found in certain commercially available signal sources, calibrators, and measuring instrument standards today. Where these products have the above characteristics in sufficient amount, they can be adapted as DTSs. Since it may not be commercially viable for industry to invest in the R&D leading to more sophisticated DTSs, there may be a role for NBS in developing prototype DTSs that would exhibit most, if not all, of the above attributes. Since the results of NBS work would be available to the whole industry, these prototypes may then become patterns for the industry to adopt and commercialize.

One of the generic research problems that NBS will address, relative to (a) above, is the generation, characterization, and measurement of time-dependent signals over a wide dynamic range. That is, NBS will undertake the development of DTSs whose stimulus and measurement parameters are programmable and known to within a specified accuracy. It is with such a DTS that the real-time measurement capabilities of electronic test equipment can be ascertained under conditions which simulate the testing of a UUT.

It is also proposed to incorporate testability schemes in the DTS to provide efficient check-out and maintenance procedures and to detect failure modes. Being potentially a complex structure of electronic modules and components, the DTS will likely require built-in-test (BIT) circuits which can diagnose improper functioning of at least the critical digital portions of the DTS electronics. Several BIT methods presently exist for the "self-checking" or "self-testing" of digital circuits [11]. These BIT circuits would not only help in diagnosing faults and minimizing the maintenance time of the DTS, but could also increase the level of confidence in the performance of the equipment as a standard (i.e., no subtle degradation effects).

6.1.2 Calibration and Characterization Methods

Several approaches and procedures are in common usage for providing calibration support of ATE [12]. As detailed in many of the papers referenced in [12], there are numerous shortcomings to the present piecemeal approach of removing instruments or built-in standards from the system for calibration at a remote metrology laboratory. Because of the need for performing maintenance and/or repair on these items, however, it is recognized that such "off-line" procedures are often very practical or may be the only viable calibration support available. In some cases, the mean-time-between-failures (MTBF) of the system is low so that the time to run a system calibration significantly reduces the available up-time for UUT testing. Nevertheless, where the MTBF of the ATE system is high enough and transport standards can be made available which are compatible (UUT/interface device adapter connectors, loading impedances, signal levels, etc.), procedures for calibrating the system on-site at the UUT/interface device adapter terminals are preferable.

The measurement data contained in this report (from the limited experimental investigation of two EQUATE stations) does not constitute a comprehensive system calibration of the these stations. However, these data are an indication that such a system calibration procedure could be used either routinely or as an occasional verification test that system specifications are being met in-situ. Various schemes for providing internal calibration tests, and associated hardware adjustments or software-generated offset and gain/attenuation corrections, are being incorporated in many ATE systems. As microcomputers are utilized more in individual instrument building blocks within a system, these internal calibration means are distributed throughout the system. Therefore, whether the system computer is directly involved as part of the stimulus and measurement capability, as in the architecture of third generation systems such as EQUATE, or whether the signal processing is more distributed, as in the architecture of "distributed intelligence" fourth generation systems, independent verification of the calibrated system performance at the UUT/interface adapter connecter plane is an important task in the metrology support of the system.

Figure 58 illustrates the method whereby the present calibration services and Measurement Assurance Program (MAP) provided by NBS for basic electrical quantities can be augmented with the capabilities of both ATE-specific and high accuracy DTSs, as described above [10]. A viable method for supplementing the present ATE calibration hierarchy would be to make use of the DTS concept. As indicated by the solid arrowed lines, the normal path of support by means of an NBS DTS is through a key standards or calibration laboratory. Commercial "roll-up" standards which serve as working accuracy DTSs (dedicated, perhaps, to a specific ATE system) are then calibrated using the NBS DTS and any other appropriate standards. The commercial DTS, in turn, is periodically used to provide a system calibration at the UUT/interface device adapter of the ATE. This periodic testing of system performance serves as a verification that built-in self-tests are maintaining the quality of the measurements of the system. The removal of certain "core" stimulus or measurement equipment or built-in standards for testing and/or calibration in a laboratory is still optional, of course, but may not be necessary.

6.2 Needs at NBS for Automated Calibration Support Systems

To assure that the metrology support of ATE system performance can efficiently be traced back to national laboratory standards at NBS, there is a considerable need at this time for developing appropriate automatic test and calibration systems. Some of the calibration services at NBS, in fact, are already automated. But these setups are primarily dedicated to providing support for the relatively few and generally fixed-value transfer standards passed between NBS and corporate level standards laboratories. As shown in figure 59, the DTS concept and calibration support strategy implies a system whereby the relatively complex DTSs can be readily maintained, i.e., well-characterized and calibrated. Because of the various kinds, ranges, and levels of calibration parameters of interest, and the need for a considerable amount of documentation, automation of the calibration support system is essential. As indicated in figure 59, desk-top or minicomputer-based systems are anticipated at NBS and at the key standards or calibration laboratory to interface with the DTS and make the necessary comparison measurements.

Starting at NBS, the appropriate national laboratory standards (item 1 in figure 59) are used to calibrate the variety of possible quantities within the capability of the NBS DTSs (item 2). By virture of attributes listed in (e) and (f) and BIT capability, the time and effort required to completely characterize the DTS can be minimized. Environmental testing of the DTS would also be performed, although it is not shown on the diagram for sake of simplicity.

At the key standards or calibration laboratory level, the commercial DTS (item 5) is calibrated against the NBS DTS. Such a laboratory has working standards (item 3) as well as precise calibrators, for example, programmable precision dc and ac sources (item 4). These items are brought into the calibration process in two ways -- (1) in conjunction with the NBS DTS, they could facilitate the calibration of the commercial DTS, and (2), more importantly, the NBS DTS may be used to calibrate the standards, calibrators, and other precise test instruments in the key laboratory. Many of the secondary standards and most of the test instruments are programmable via standard buses (e.g., IEEE-488). The DTS would therefore perform the task of updating the corrections to the inventory of standards and test equipment. Either during or between update cycles with the NBS DTS, the automatic test systems would be used to verify or to make corrections to the commercial DTS which can be of the form of "roll-up" standards or "calibration consoles" which serve a particular class of ATE.

The on-site ATE systems (item 6) are then tested by way of the commercial DTS (item 5) to provide the needed step in the traceability path for stimulus and measurement parameters at the interface of the ATE system and the UUT. If possible, these calibrations of the ATE system should include the effects of UUT interface device adapters, cables, connectors, etc. Due to the large number of such special interface hardware, however, it may be impractical to include the effects in every case, but at least these tests will verify stimulus or measurement values at the UUT connector panel.

6.3 Recommendation for Future NBS ATE Efforts

Having demonstrated the need for, and viability of, in-situ ATE performance verification by means of well-characterized and calibrated sources used as transport standards, we propose to continue and expand the work. In view of the great leverage obtained by a properly performing ATE system on military weapons readiness, an expanded NBS program is felt to be of significant cost effectiveness to the DoD. The beneficial results of continuing this work are the improvements in system self-calibration and self-test programs, and maintaining better test consistency, uniformity, and traceability of measurements made by DoD's large inventory of ATE systems.

6.3.1 Near-Term Extensions of Present JLC 30702 Project

Immediate efforts will be directed at extending the field studies that have been carried out by NBS staff at both the Gaithersburg and Boulder laboratories. The details of the proposed work are outlined in the following tasks:

(1) <u>Field Studies of Selected ATE Systems</u>

Continue the field studies of selected ATE systems, using a well-characterized two-channel source of non-sinusoidal signals, the improved pulse waveform stimulus source, and the dc-10 MHz source characterized previously.

(2) <u>Dual-Channel Signal Source For On-Site Calibration of ATE</u>

Procure a signal source capable of generating two channels of periodic waveforms, both sinusoidal and non-sinusoidal with frequencies up to 100 kHz. Characterize this source for stability, temperature dependence, and other environmental effects. Establish traceability of this source by calibration against higher echelon standards at NBS.

(3) <u>Improved Characterization Methods for Signal Sources</u>

Continue and expand the investigation of improved characterization methods for sources of periodic, sinusoidal, and non-sinusoidal signals. Initially consider conventional techniques, including the rms amplitude measurements using thermal converter-based automatic measurement systems. Also, conduct theoretical and experimental investigations into viable methods for accurately characterizing non-sinusoidal periodic waveshapes. It is anticipated that the study will establish some fundamental principles of waveshape characterization. It should identify trade-offs of accuracy vs frequency and waveshape (harmonic content). Prospective characterization methods for both sinusoidal and non-sinusoidal signal sources are by means of digital sampling techniques. Technology currently under investigation at NBS for application to non-sinusoidal power measurements will be used to extend voltage measurements to fundamental frequencies up to 100 kHz. It is planned for the sampling voltage measurements to extend to frequencies up to 1 MHz (10th harmonic of 100 kHz) and cover amplitudes from 100 mV rms to 100 V rms. The accuracy goal (at the 10 V rms level) is ±0.05 percent of FSR, dc to 100 kHz, degrading to 0.5 percent at 1 MHz.

(4) Improved Pulse Waveform Stimulus Source

Modify the pulse waveform stimulus source that was used in the initial ATE field tests to provide improved waveform amplitude control and accuracy. Construct a reference flat pulse generator module for improved waveform amplitude control in a dynamic sense. Initially, this module will generate a 1.0 V (open circuit) step-like waveform with 0.6 ns transition duration with a source impedance of 50.0 Ω. Begin work on a set of lossy filters to be used with the flat pulse generator to allow pulse transition durations in the range from 1 ns to 1 μs nominally in a 1-2-5 sequence. Characterize this improved pulse stimulus source and establish its traceability. Begin work to improve the drive circuitry for the NBS Pulse Measurement System Sampling Head. These improvements are expected to yield substantial increases in system resolution and stability.

(5) Improved Automatic Pulse and Measurement System

Improve the existing Automatic Pulse and Measurement System (APMS) which is used to characterize and calibrate the Pulse Waveform Stimulus Generator. The latter is the signal source for field studies of ATE stations. APMS is a computer-based equivalent-time sampling analyzer capable of recording, measuring, and analyzing waveforms with transition duration (rise times) in the sub-nanosecond region. In order to establish NBS traceability of the waveform measurement portion of ATE systems, it is necessary to up-grade this NBS in-house support facility. The current system is not adequate to develop standards and traceability requirements for state-of-the-art ATE used by DoD. The improved system should be capable of establishing pulse duration (and pulse transition duration) within 1 percent from 10 ps to 1 μs, pulse delay times within 1 percent from 5 ps to 1 μs, and pulse amplitudes from 10 mV to 10 V within 1 percent.

6.3.2 Longer Range Program

The tasks described above will build a foundation at NBS for providing basic metrology for supporting both present and future ATE systems used by the DoD. We also propose a longer range effort which would develop similar support for other critical measurement parameters in the low frequency and pulse domain, as well as coverage of RF, microwave/millimeter wave, and optical regions of the electromagnetic spectrum. For example, an RF signal source capable of generating signals with amplitudes from 0.1 to 7 V rms and frequencies up to 100 MHz will be accurately characterized for stability, temperature dependence, and other environmental effects, and its traceability rigorously established by calibration against higher echelon laboratory standards at NBS. This source, and other high frequency dynamic transport standards to be developed, will also need automatic calibration systems at NBS for proper support as described in section 6.2.

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Special appreciation is expressed to the editorial and secretarial staff who produced this report and typed the manuscript: Bonnie Smith, Betty A. Oravec, and Daria A. Edwards.

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[4] IEEE Standard - Pulse Terms and Definitions, IEEE Std. 194-1977, July 1977.

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[8] Test Station, Electronic Equipment, AN/USM-410 (XE-3)(V), ET&DL 75-04513-002, Frequency Control and Signal Processing Devices Technical Area, U.S. Army Electronics Technology and Devices Laboratory, U.S. Army Electronics Command, 13 April 1976, pp. 42.

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[11] J. B. Clary and R. A. Sacane, Self Testing Computers, IEEE Computer, Vol. 12, (Oct. 1979).

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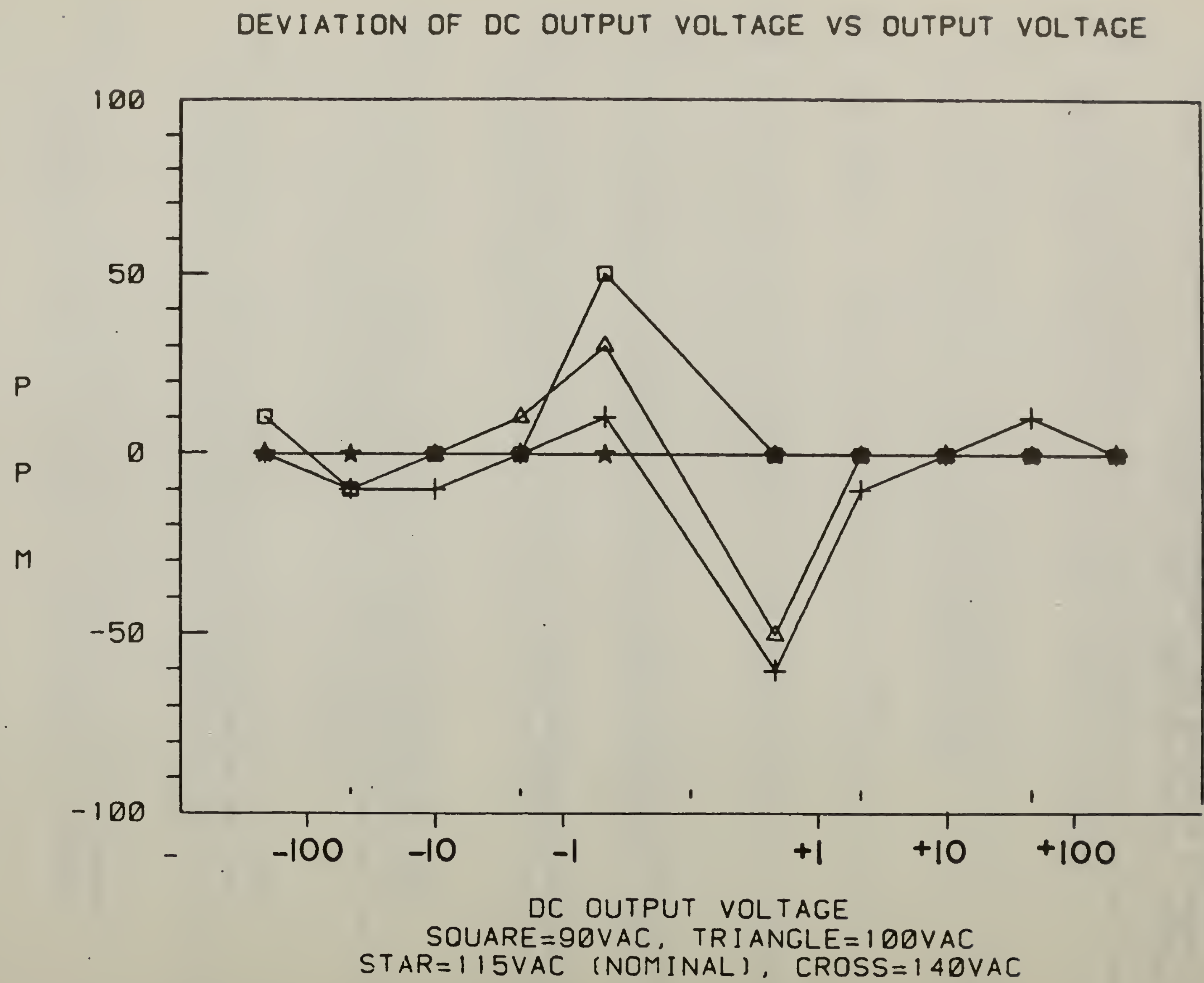


Figure 1. The change in the dc output voltage as a function of power line voltage. Note that the x-axis is a logarithmic axis in both the positive and negative directions. This convention is used to display a wide range of dc voltages in several of the plots that follow.

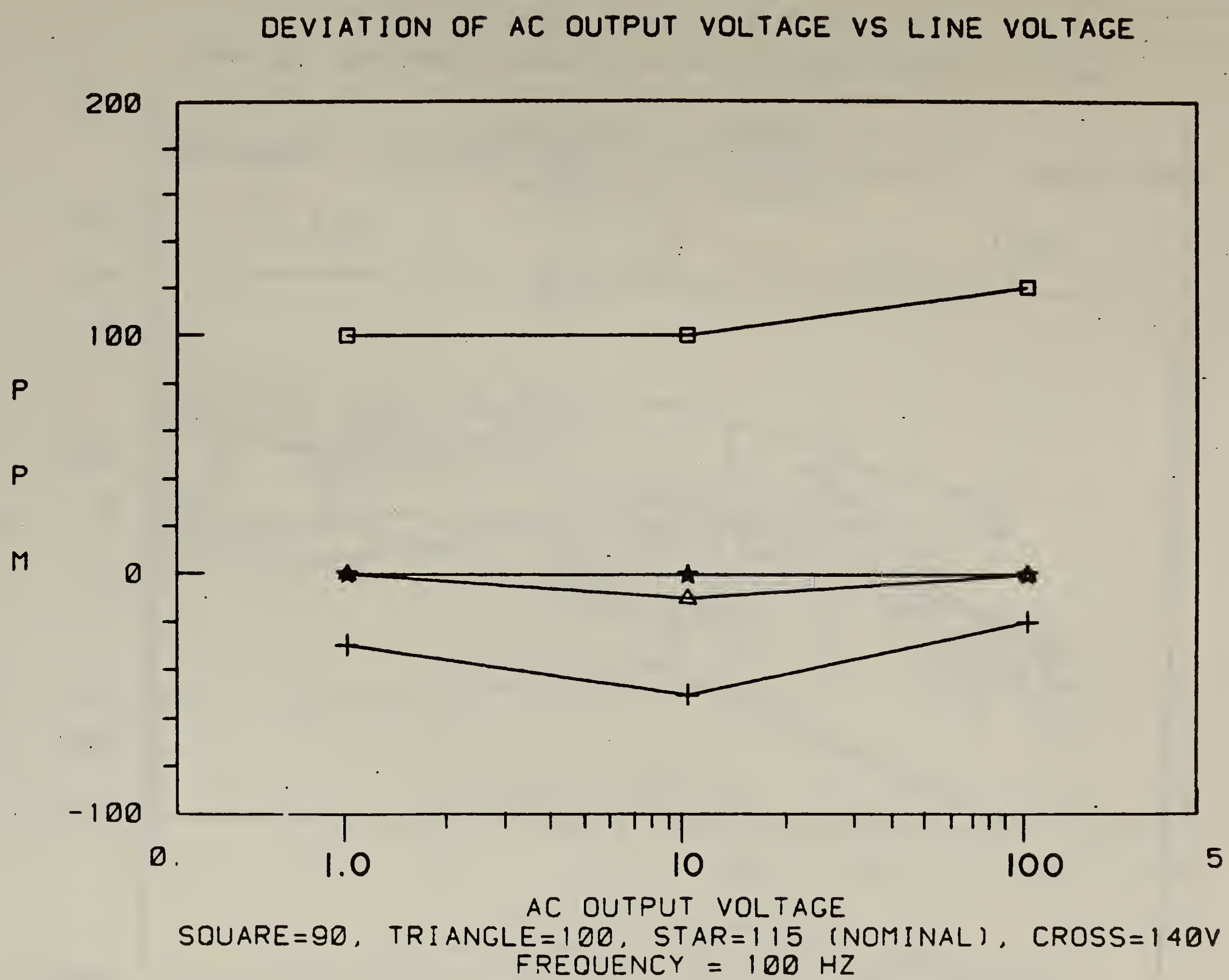


Figure 2a. The change in the ac output voltage of the source with the output at 1.0, 10.0, and 100.0 V and a frequency of 100 Hz.

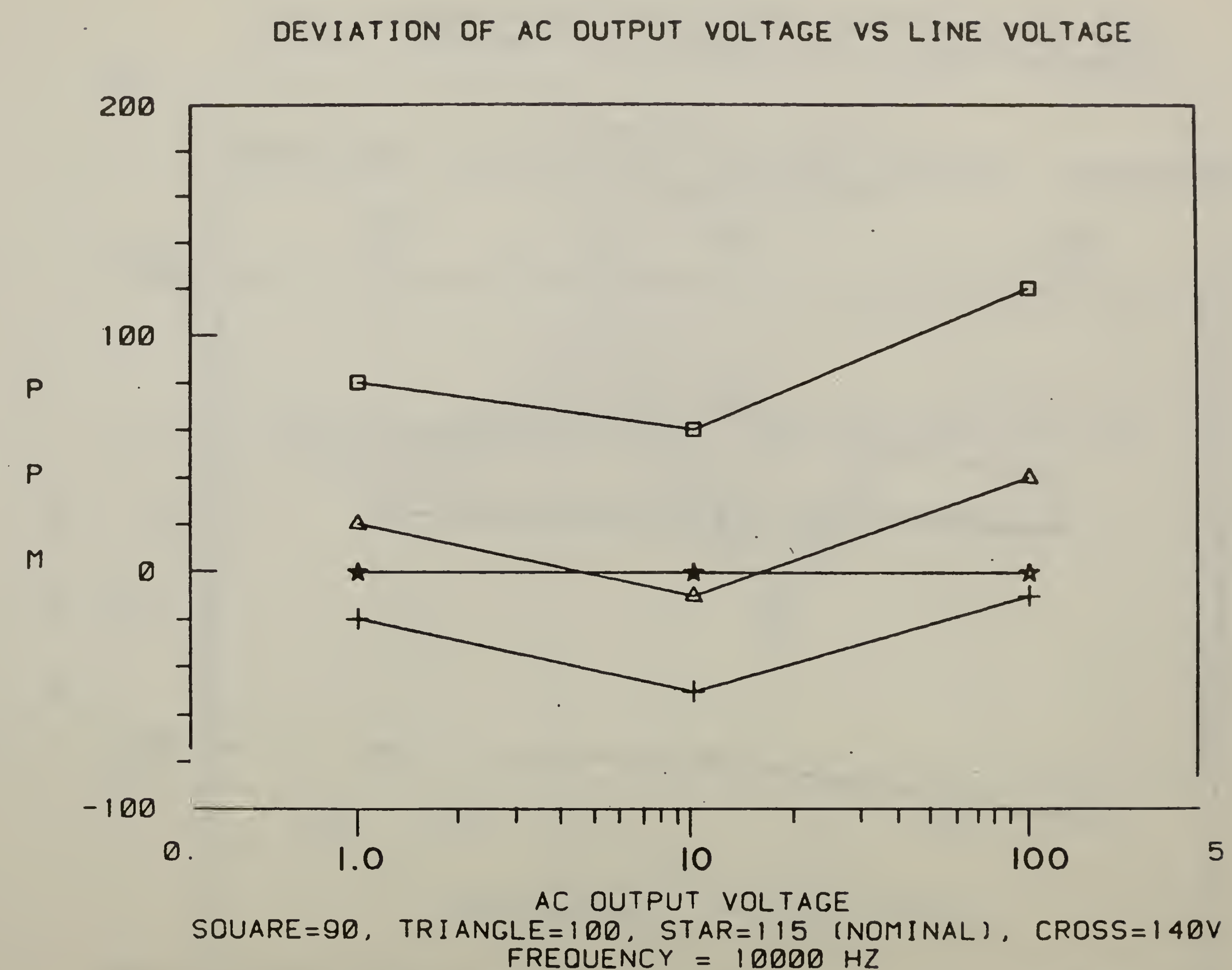


Figure 2b. The same as figure 2a except the output voltage is 10 kHz.

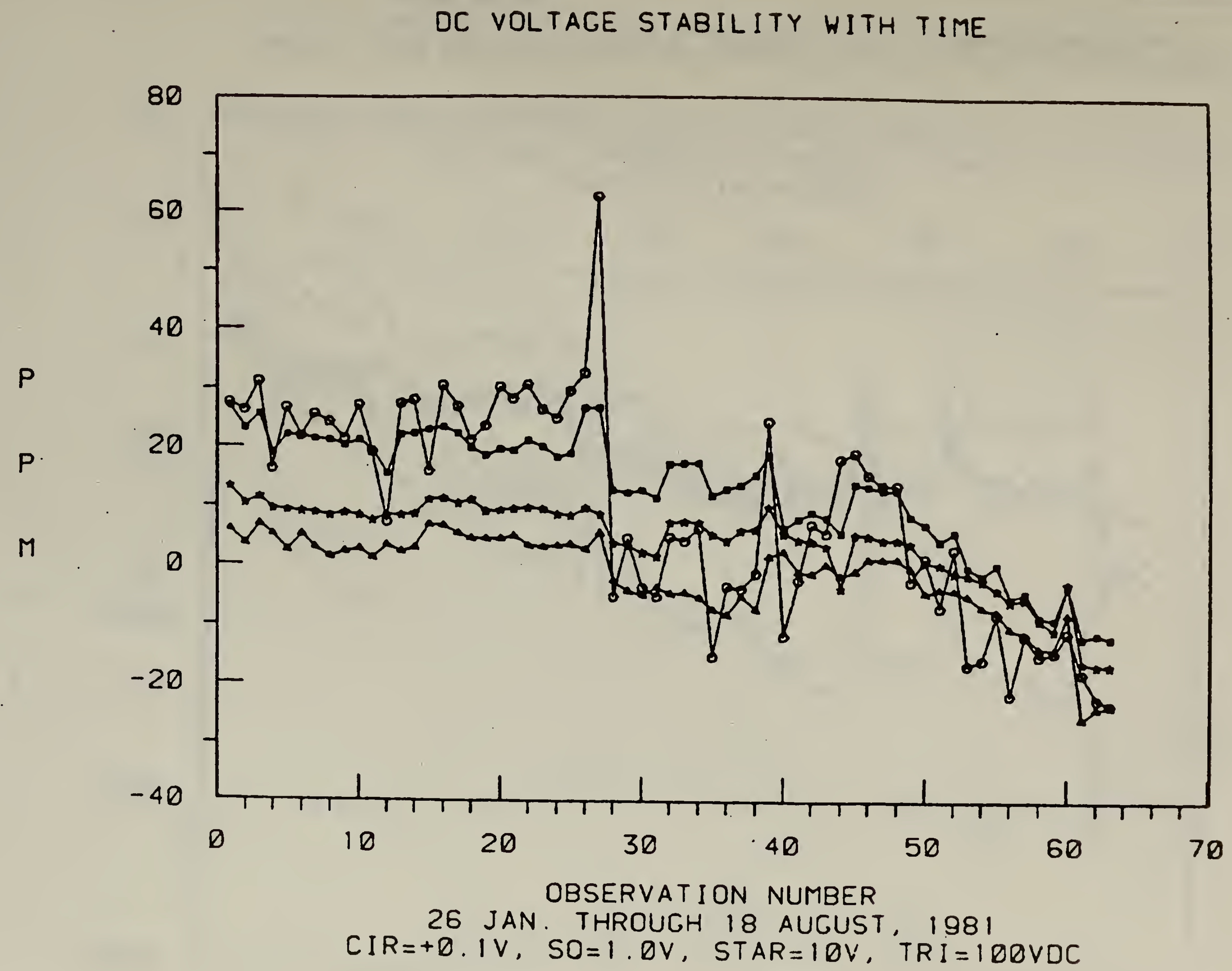


Figure 3. The change of the dc voltage output at four selected voltages over a period of approximately seven months.

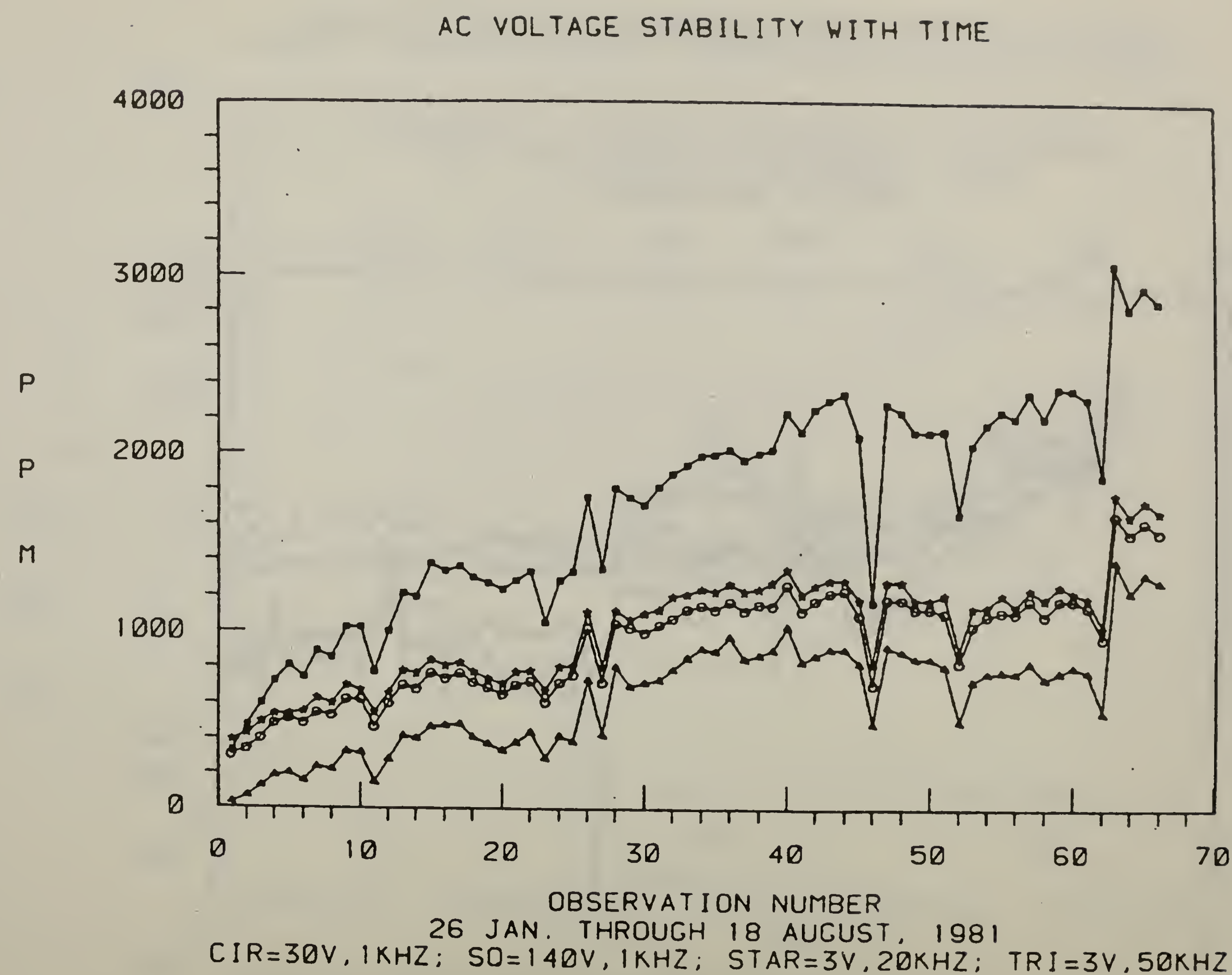


Figure 4. The change of the ac voltage output of the source at four selected voltage and frequency combinations over a period of approximately seven months.

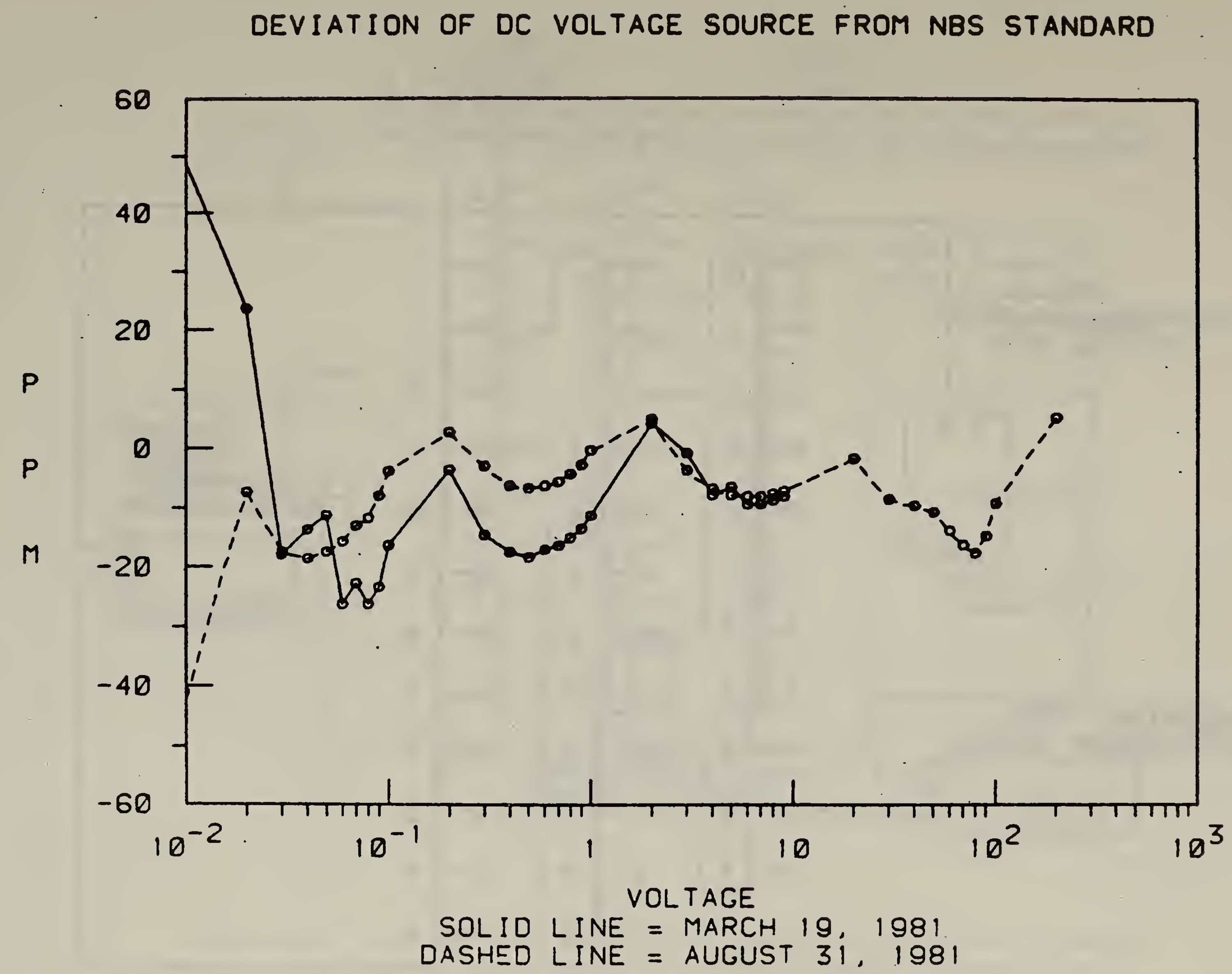


Figure 5. The difference, on two occasions, between the dc output voltage of the source and the NBS Legal Volt as maintained by the Electrical Measurements and Standards Division of NBS.

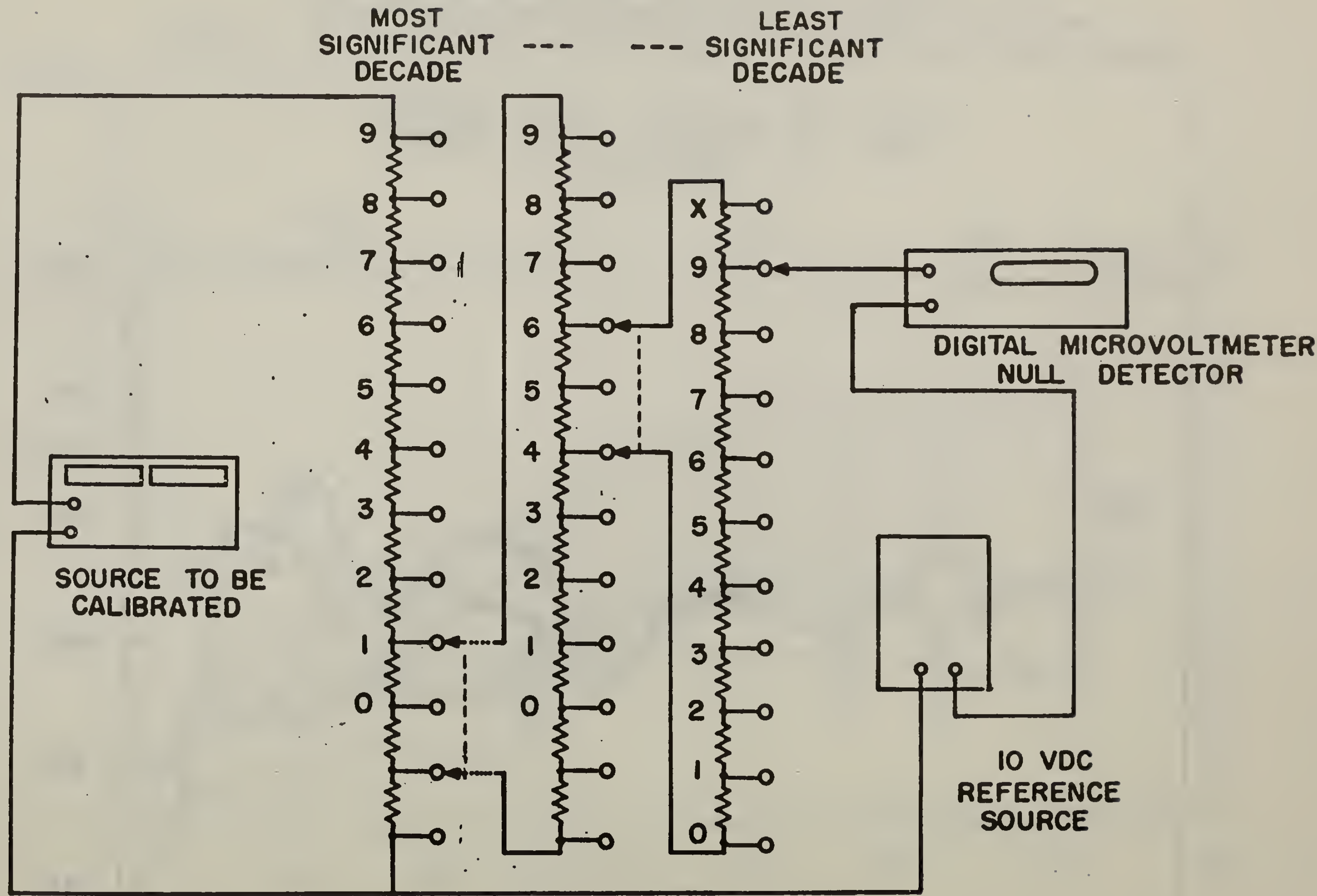


Figure 6a. The interconnection used to determine the difference between the NBS Legal Volt and the source for the voltage range of 10 to 200 V dc.

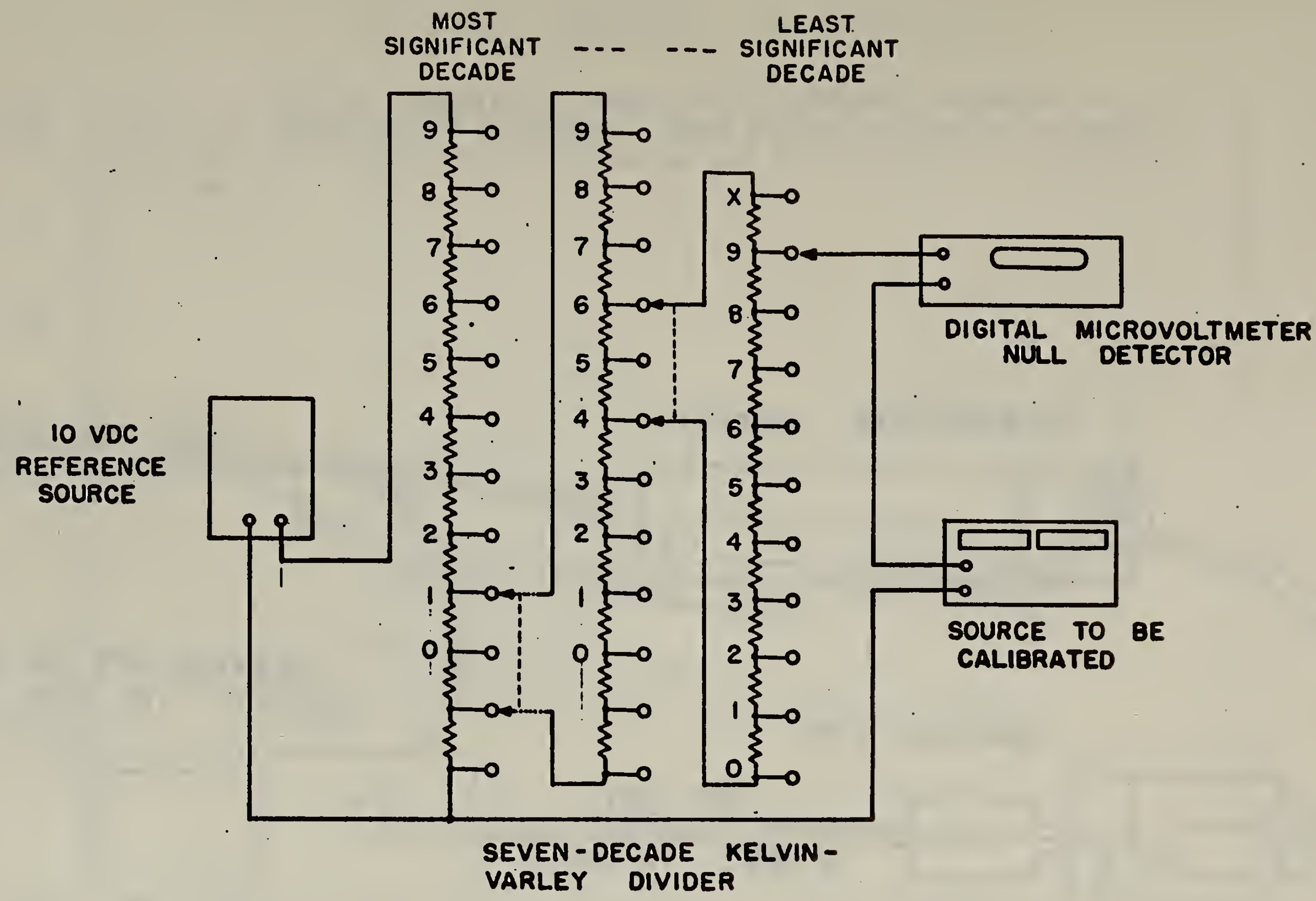


Figure 6b. The interconnection used to determine the difference between the NBS Legal Volt and the source for the voltage range of 0 to 10 V dc.

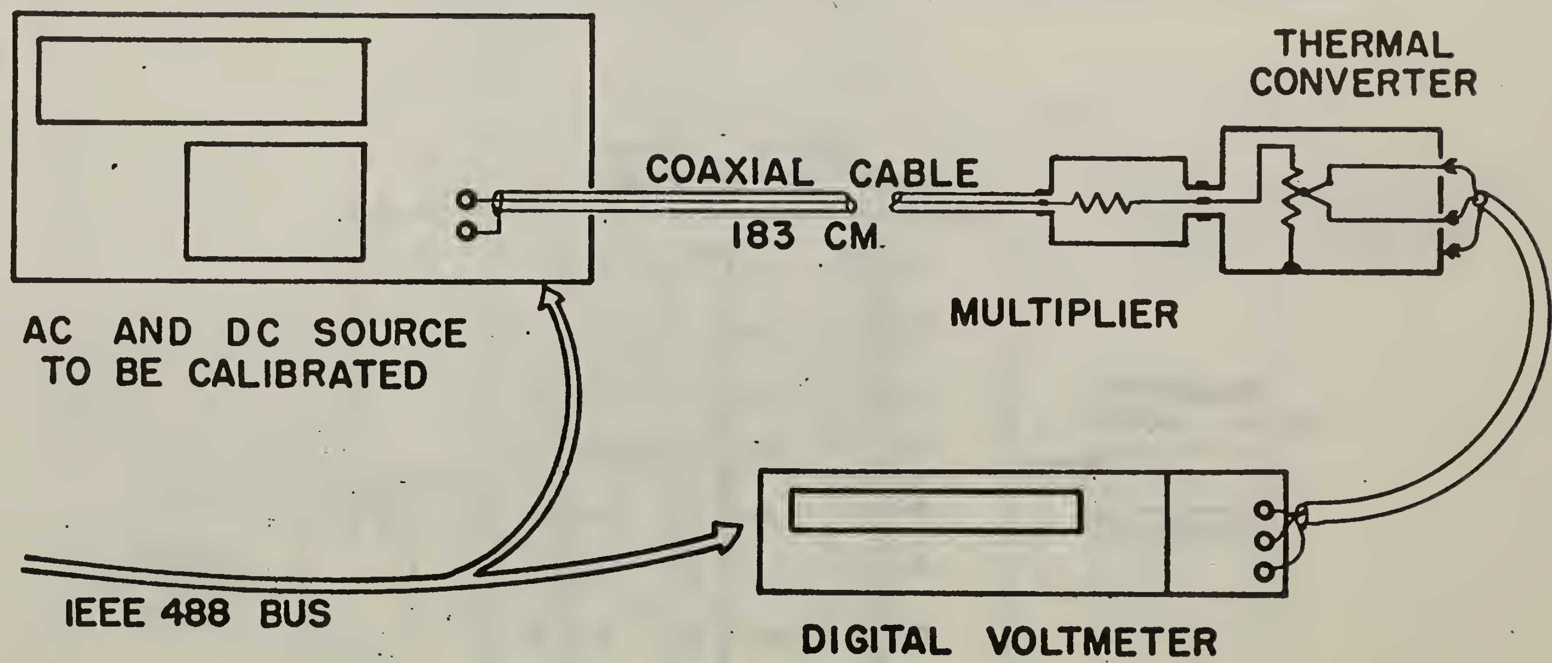


Figure 6c. The system used to determine the ac voltage of the source in terms of the dc voltage. Both the source and the voltmeter may be controlled by means of the IEEE-488 interface.

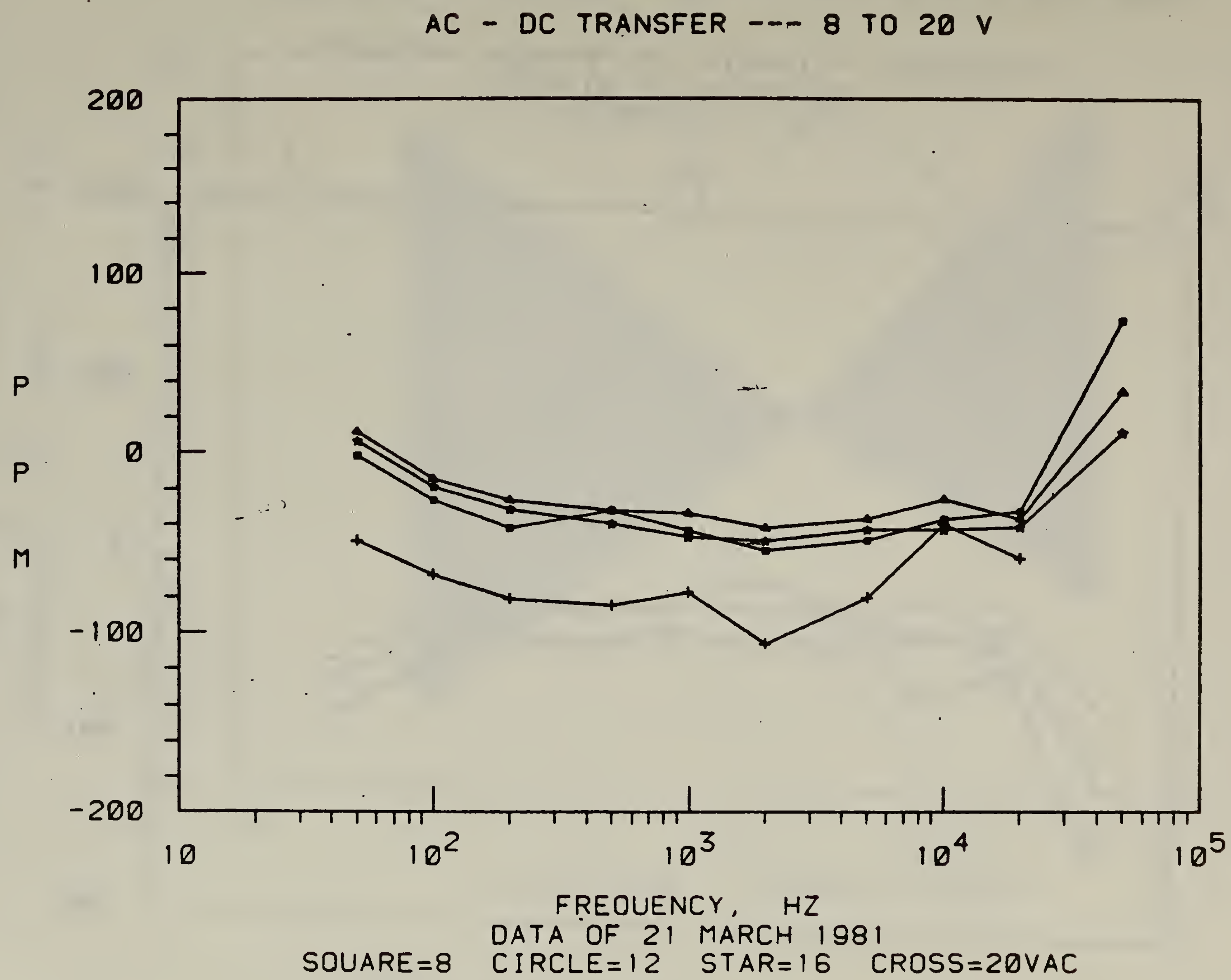


Figure 7a. The results of the ac-dc intercomparison over the range of 8 to 20 V ac and over the frequency range of 50 Hz to 50 kHz.

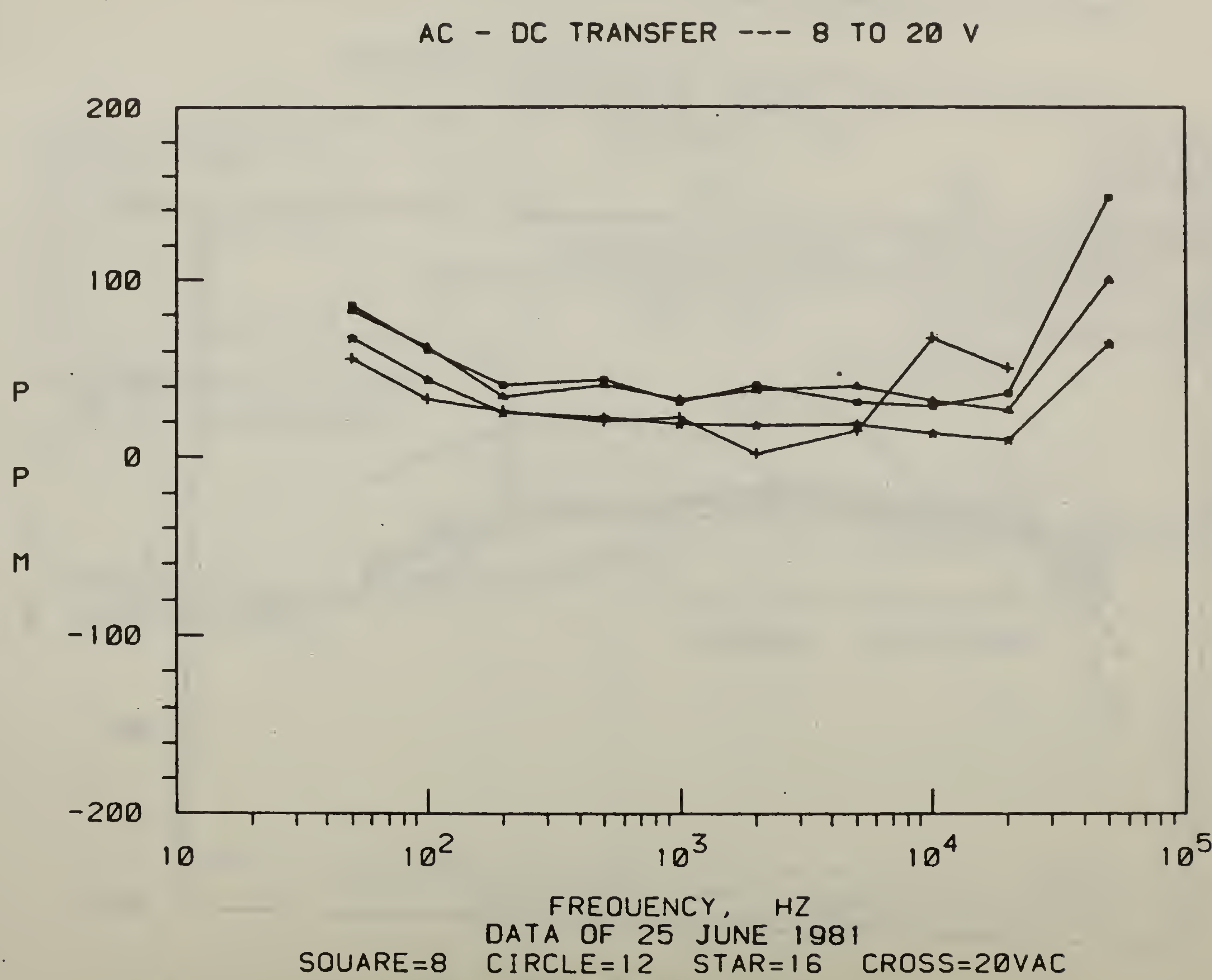


Figure 7b. The same intercomparison as shown in figure 6a performed three months later.

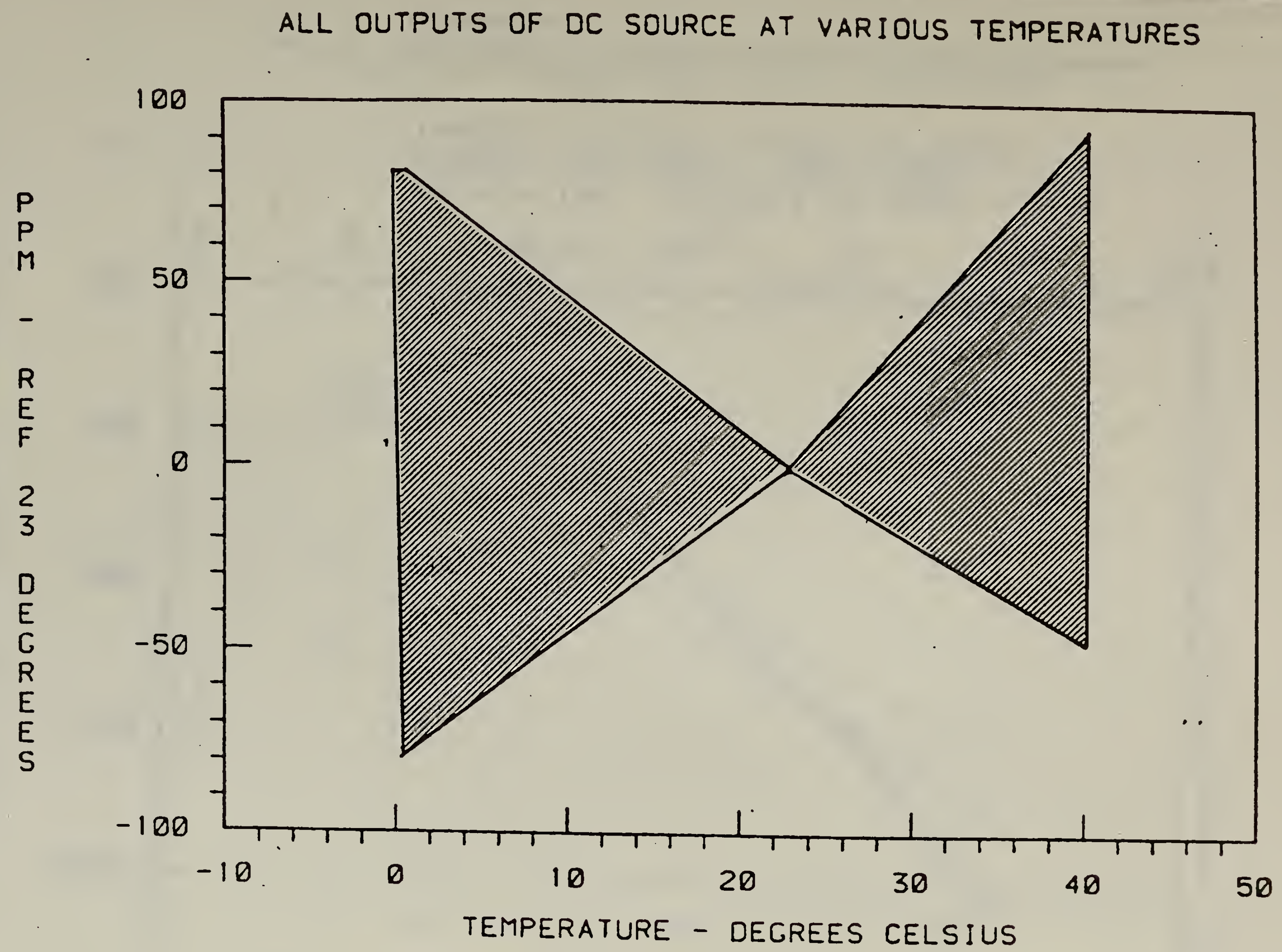


Figure 8. The limits in the changes of the output voltage of the source over the temperature range 0° to 40°C.

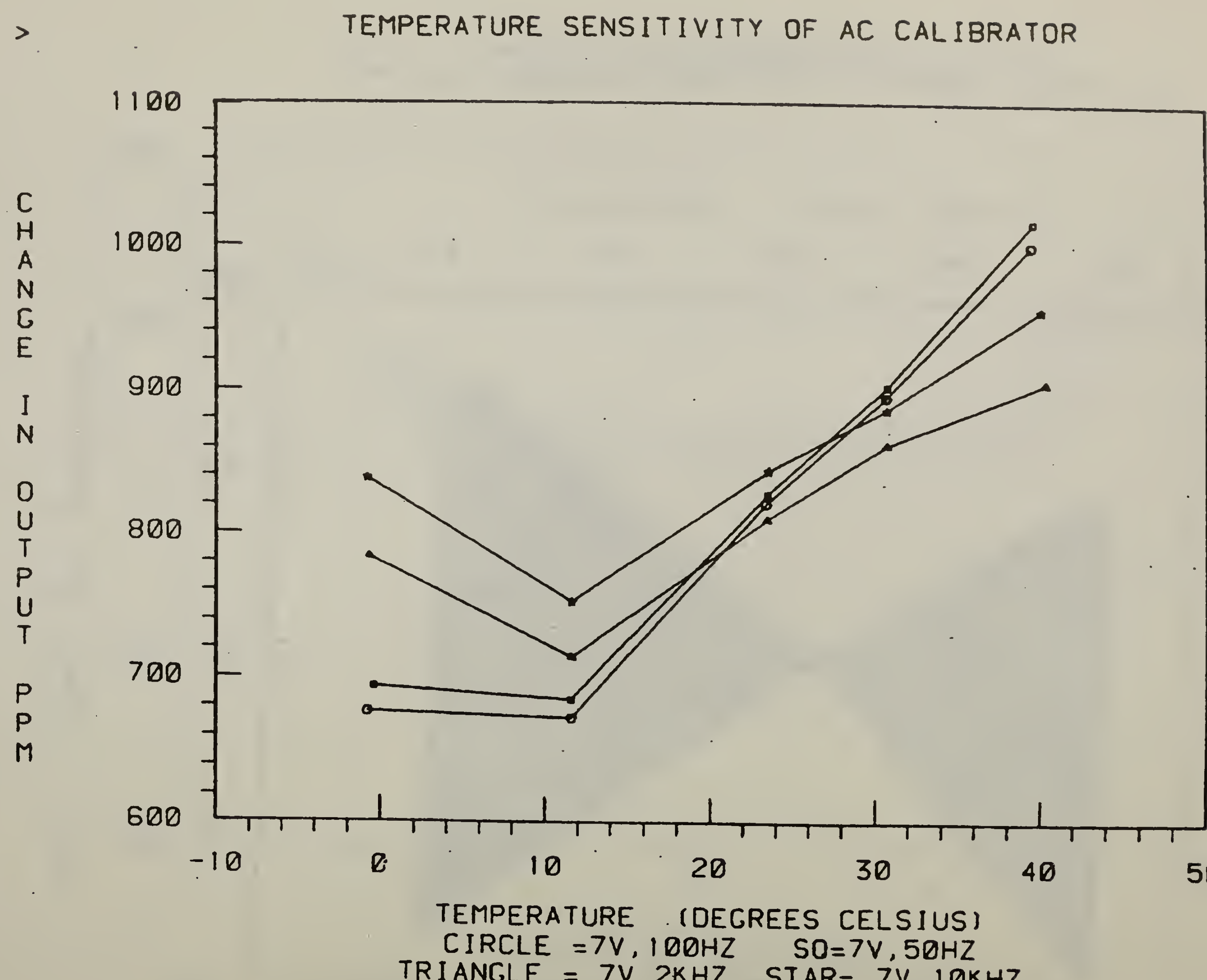


Figure 9. The change in ac output voltage as a function of ambient temperature.

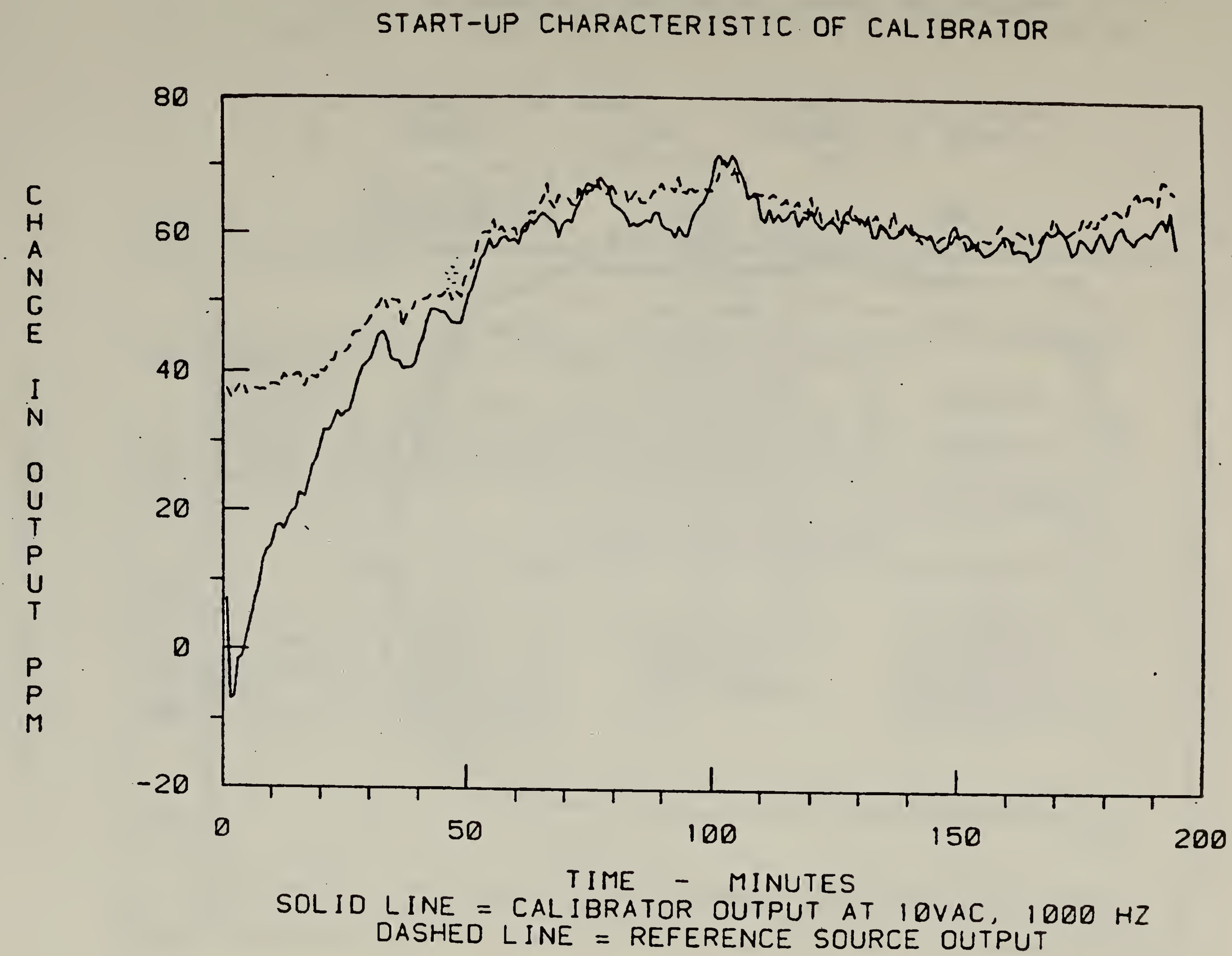


Figure 10. The change in the ac output voltage of the source as a function of time after the source is powered.

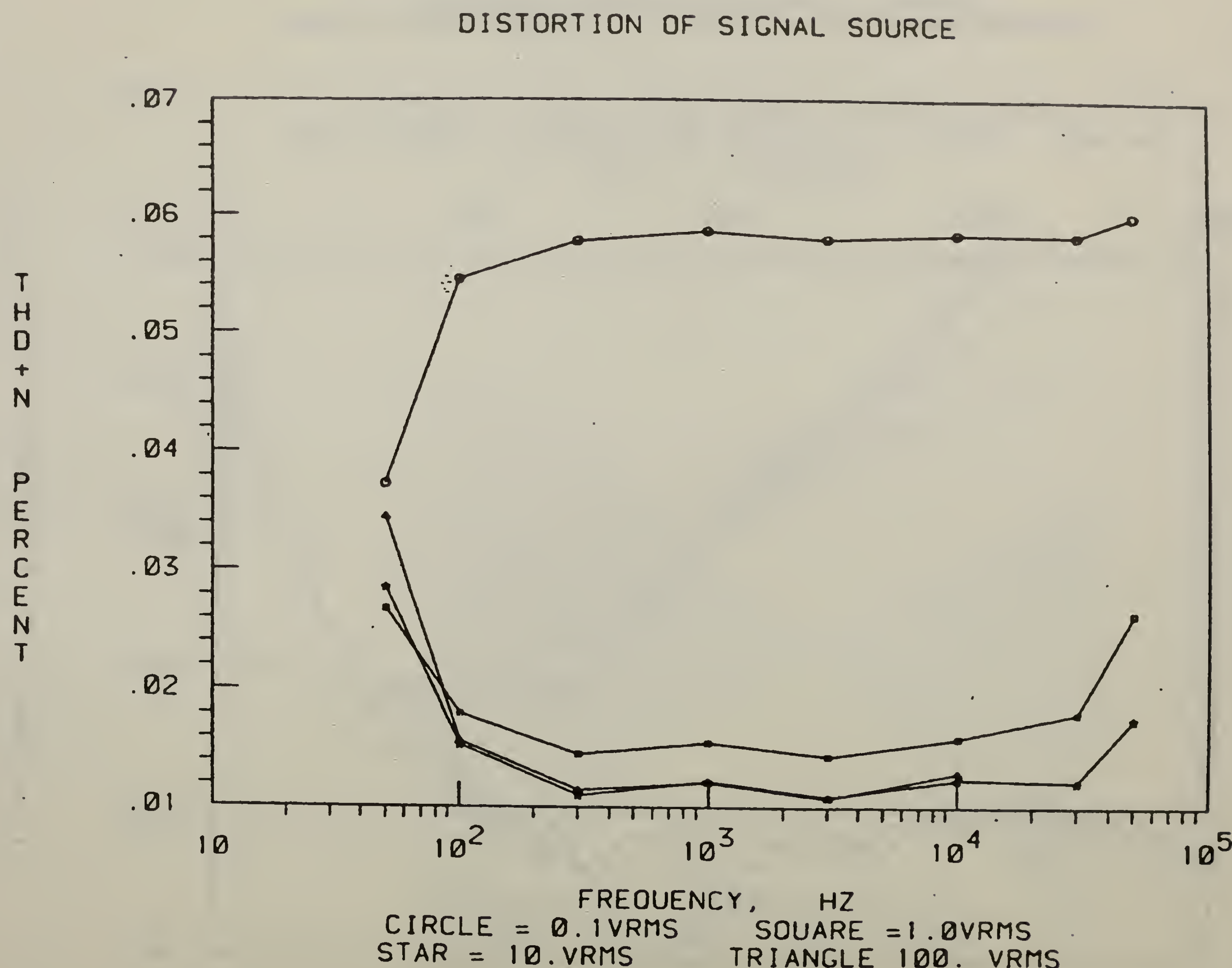


Figure 11. The total harmonic distortion and noise (THD + N) of the ac source as a function of frequency and amplitude.

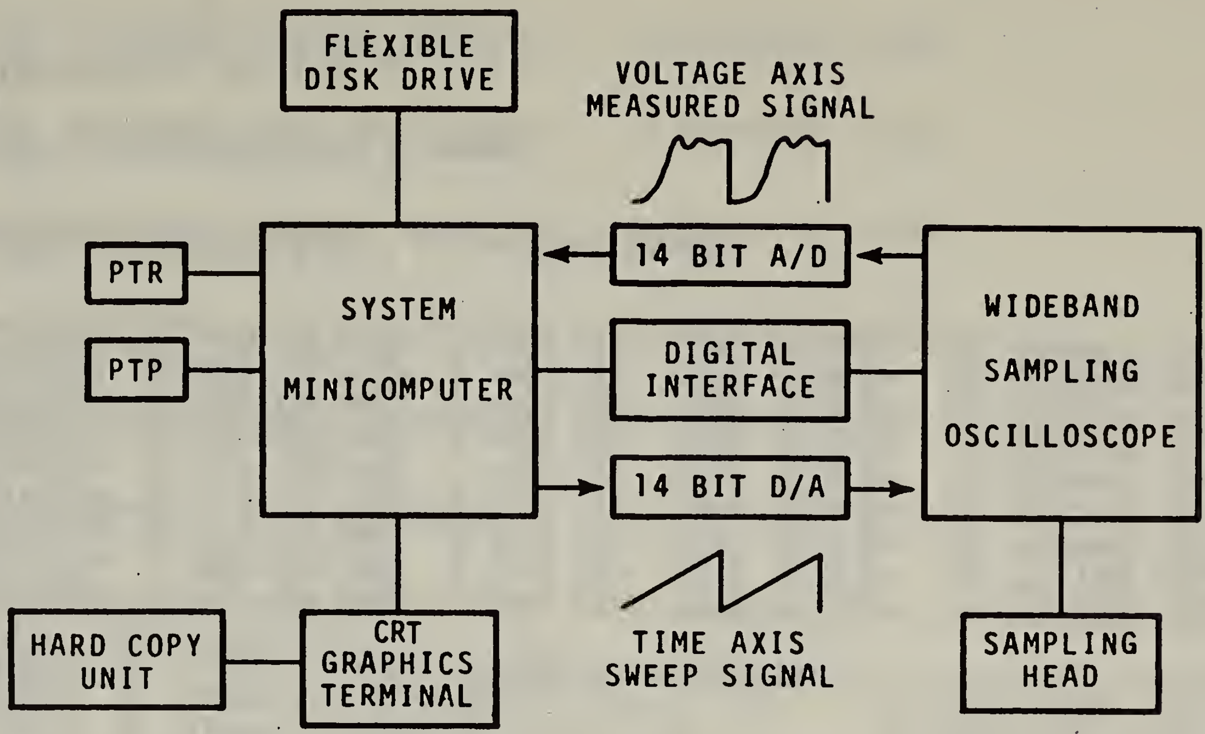


Figure 12. NBS Automatic Pulse Measurement System (APMS) block diagram.

```
TCALI
*SET THE S.O. TIME BASE TO THE SWEEP SPEED YOU INTEND TO USE
FOR THE 10%-90% RISETIME MEASUREMENT.  APPLY A SIGNAL OF
KNOWN FREQUENCY TO THE SAMPLER SUCH THAT THE S.O. DISPLAY
CONTAINS BETWEEN 5 AND 15 SIGNAL PERIODS.  CENTER THE SIGNAL
VERTICALLY ABOUT THE 4TH CM ON THE S.O.
THE SIGNAL FREQUENCY IN GHZ=?                              .05
DO YOU WANT CALIBRATION DONE BETWEEN SEQUENTIAL POSITIVE OR
NEGATIVE WAVEFORM SLOPES? (1=+, 0=-)                       1
NUMBER OF DUMMY SWEEPS=?                                   25
NUMBER OF SWEEP AVERAGES=?                                 200
NUMBER OF LEAST-SQUARES CURVE FIT POINTS=?                 11

BETWEEN  0.387 CM AND  1.398 CM, TIME SCALE=  19.782800 NS/CM
BETWEEN  1.398 CM AND  2.412 CM, TIME SCALE=  19.731100 NS/CM
BETWEEN  2.412 CM AND  3.413 CM, TIME SCALE=  19.993900 NS/CM
BETWEEN  3.413 CM AND  4.412 CM, TIME SCALE=  20.026700 NS/CM
BETWEEN  4.412 CM AND  5.437 CM, TIME SCALE=  19.528000 NS/CM
BETWEEN  5.437 CM AND  6.439 CM, TIME SCALE=  19.963200 NS/CM
BETWEEN  6.439 CM AND  7.407 CM, TIME SCALE=  20.676300 NS/CM
BETWEEN  7.407 CM AND  8.440 CM, TIME SCALE=  19.377600 NS/CM
BETWEEN  8.440 CM AND  9.418 CM, TIME SCALE=  20.446000 NS/CM

AVERAGE TIME SCALE=  19.947300 NS/CM

TIME CALIBRATION FILE NAME?
T1
STOP 999
```

Figure 13. Typical run time terminal dialog for TCAL time axis calibration program.

```
VCALI
*NOMINAL VERTICAL SCALE FACTOR IN MV/CM =?100.
NUMBER OF SWEEP AVERAGES? NOTE: 1024 AVERAGES/SWEEP.50

APPLY THE MINIMUM DC VOLTAGE DESIRED TO THE SAMPLER
AND ADJUST THE VERTICAL POSITION CONTROL TO POSITION
THE BASELINE ON THE LOWEST GRATICULE LINE.  TYPE ANY KEY
TO BEGIN THE MEASUREMENT.11

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1

NOW INCREASE THE DC VOLTAGE    0.999990E  2MV.
THEN, TYPE ANY KEY.1
IN CM. #      1 , THE SCALE FACTOR IS     0.100952E  3 MV/CM
IN CM. #      2 , THE SCALE FACTOR IS     0.100266E  3 MV/CM
IN CM. #      3 , THE SCALE FACTOR IS     0.100213E  3 MV/CM
IN CM. #      4 , THE SCALE FACTOR IS     0.100187E  3 MV/CM
IN CM. #      5 , THE SCALE FACTOR IS     0.100835E  3 MV/CM
IN CM. #      6 , THE SCALE FACTOR IS     0.100266E  3 MV/CM
IN CM. #      7 , THE SCALE FACTOR IS     0.995725E  2 MV/CM
IN CM. #      8 , THE SCALE FACTOR IS     0.100395E  3 MV/CM

THE MEAN SCALE FACTOR IS    0.100336E  3MV/CM
VERT CALIB FILE NAME?
V1
STOP 999
```

Figure 14. Typical run time terminal dialog for VCAL voltage axis calibration program.

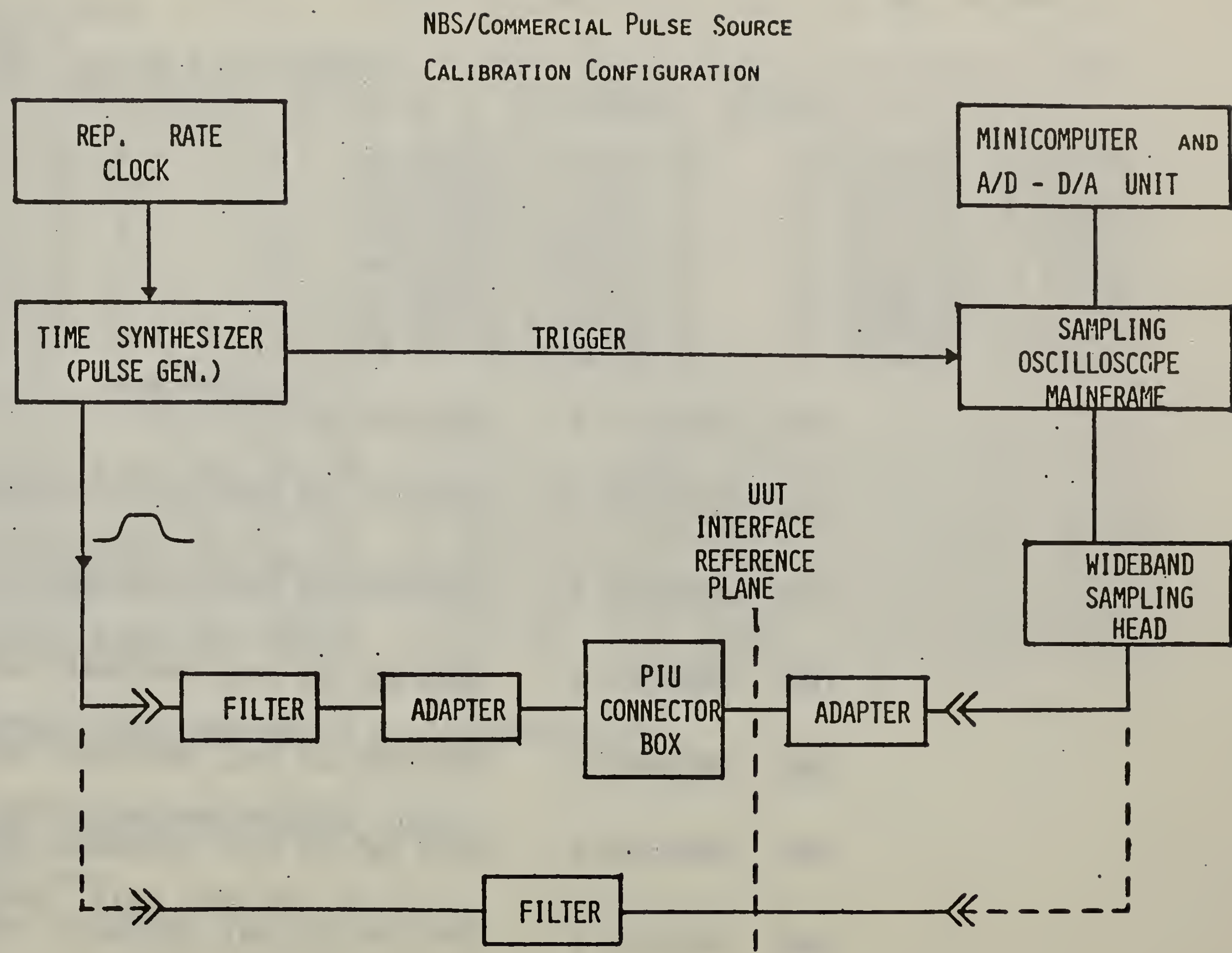


Figure 15. NBS/commercial pulse source calibration configuration.

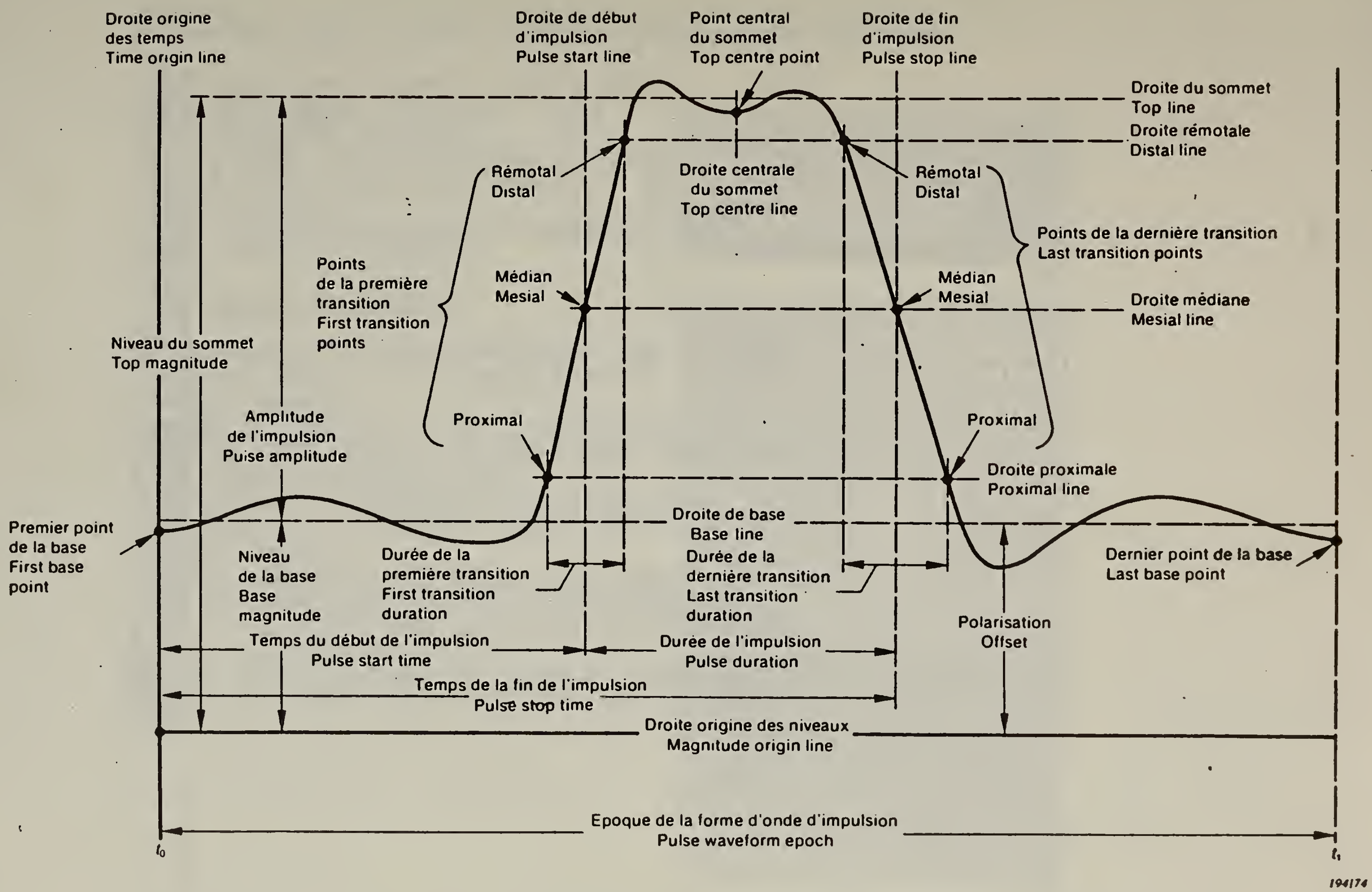


Figure 16. Standard pulse terminology and definitions for a single pulse.

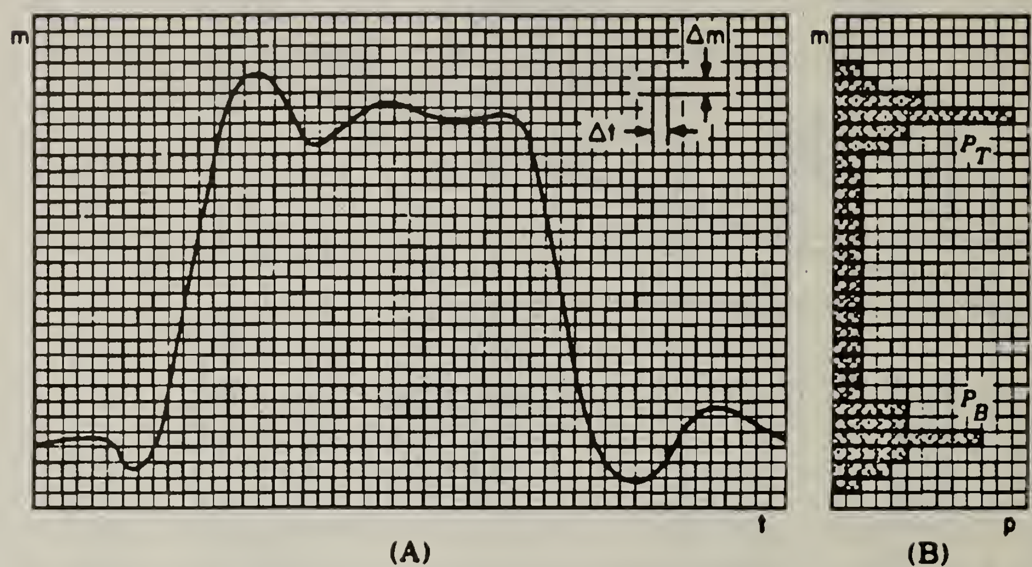


Figure 17. Graphical determination of occurrence density A - pulse waveform with superimposed grid. B- probability density histogram.

```
GMEASI
*SAMPLING OSCILLOSCOPE GENERAL MEASUREMENT PROGRAM

# OF WAVEFORM POINTS ? (2048 MAX.)    2048
VERTICAL SCALE IN MV/CM ? 100.
TIME SCALE IN NSEC/CM ?   20.
DO YOU WANT TO AUTOMATICLLY CORRECT FOR SCOPE
VERT & HORIZ NONLINEARITIES?
(1=YES,0=NO)1
FIRST ORDER NONLINEARITY CORRECTIONS
VERT CALIB FILE NAME?
V1
TIME CALIB FILE NAME?
T1
DO YOU WANT TO STRAIGHTEN OUT THE INITIAL
SAMPLING EFFICIENCY NONLINEARITY?
(1=YES, 0=NO)1
NUMBER OF POINTS TO BE LINEARIZED?5
TYPE OF DATA SCAN? (1=SWEEP SEQ, 0=PT.SEQ)1
# OF SWEEP AVERAGES?200
DO YOU WANT TO MEASURE THE BASELINE
AND REMOVE IT FROM THE WAVEFORMS?
(1=YES, 0=NO)1
SET UP OSCILLOSCOPE TO DISPLAY BASELINE ONLY
TYPE OF BASELINE? (1=DC, 0=WAVEFORM)0
TYPE 1 TO START THE BASELINE MEASUREMENT1
YDC=    0.203526E  3
SET UP OSCILLOSCOPE TO DISPLAY WAVEFORM TO BE MEASURED
TYPE 1 TO START THE WAVEFORM MEASUREMENT1
```

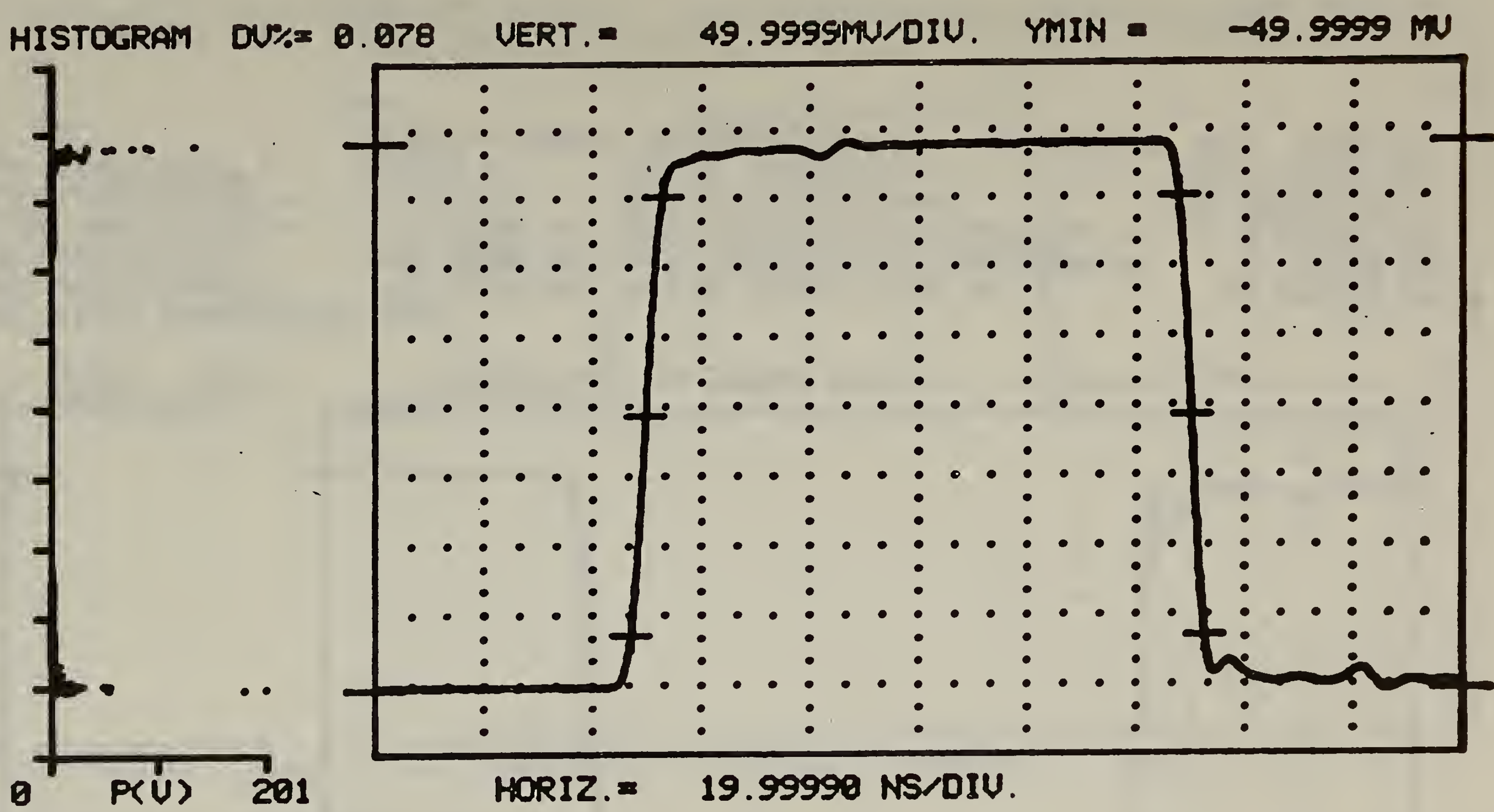
Figure 18. Typical run time terminal dialog for GMEAS pulse waveform acquisition program.

```
PWA
RLOD PTDUMB&
* .MAIN 000440
PWAI
*THIS PROGRAM MEASURES THE PARAMETERS OF A SINGLE PULSE WAVEFORM
STORED ON A FILE. NF=2048 MAX. 2 TIME EPOCHS MAY BE USED.
IT IS DESIGNED FOR USE WITH CLEAN, NOISE-FREE WAVEFORMS
THE PULSE MUST BE UNIFORM, I.E. THE BEGINNING BASELINE
AND THE ENDING BASELINE ARE ASSUMED TO BE THE SAME
THE RINGING ON THE BASELINE AND/OR TOPLINE MUST BE
SMALL ENOUGH THAT IT DOES NOT CROSS THE 10% OR 90% LEVELS
THE RESULTS ARE AUTOMATICALLY  PLOTTED.

WILL YOU INPUT 1 OR 2 WAVEFORMS?                1
WAVEFORM ARRAY FILE NAME =?
T100
    2048 DATA POINTS
TIME WINDOW IS      0.199999E  3 NS
SAMPLE SPACING IS     0.976550E -1 NS
PRESET HISTOGRAM LIMIT IS NF/100 =       20

FIRST POINT =      -0.237519E  1
LAST POINT =       0.644686E  0
MIN. VALUE =      -0.413318E  1
MAX. VALUE =       0.390925E  3
0% HISTOGRAM MODE =       -0.212702E  1
WITH      201 OCCURANCES FOUND AT I =        7
100% HISTOGRAM MODE =       0.389845E  3
WITH      134 OCCURANCES FOUND AT I =       509
HISTOGRAM SCANNED TOP & BOTTOM 20%
     512 SLICING SEGMENTS WERE USED
THE SLICING INTERVAL USED WAS DV =     0.308639E  0 MV OR
    0.781240E -1 %
IS HISTOGRAM ACCEPTABLE? (1=YES,0=NO)1
```

Figure 19. Typical run time terminal dialog for PWA2KA pulse waveform analysis program.

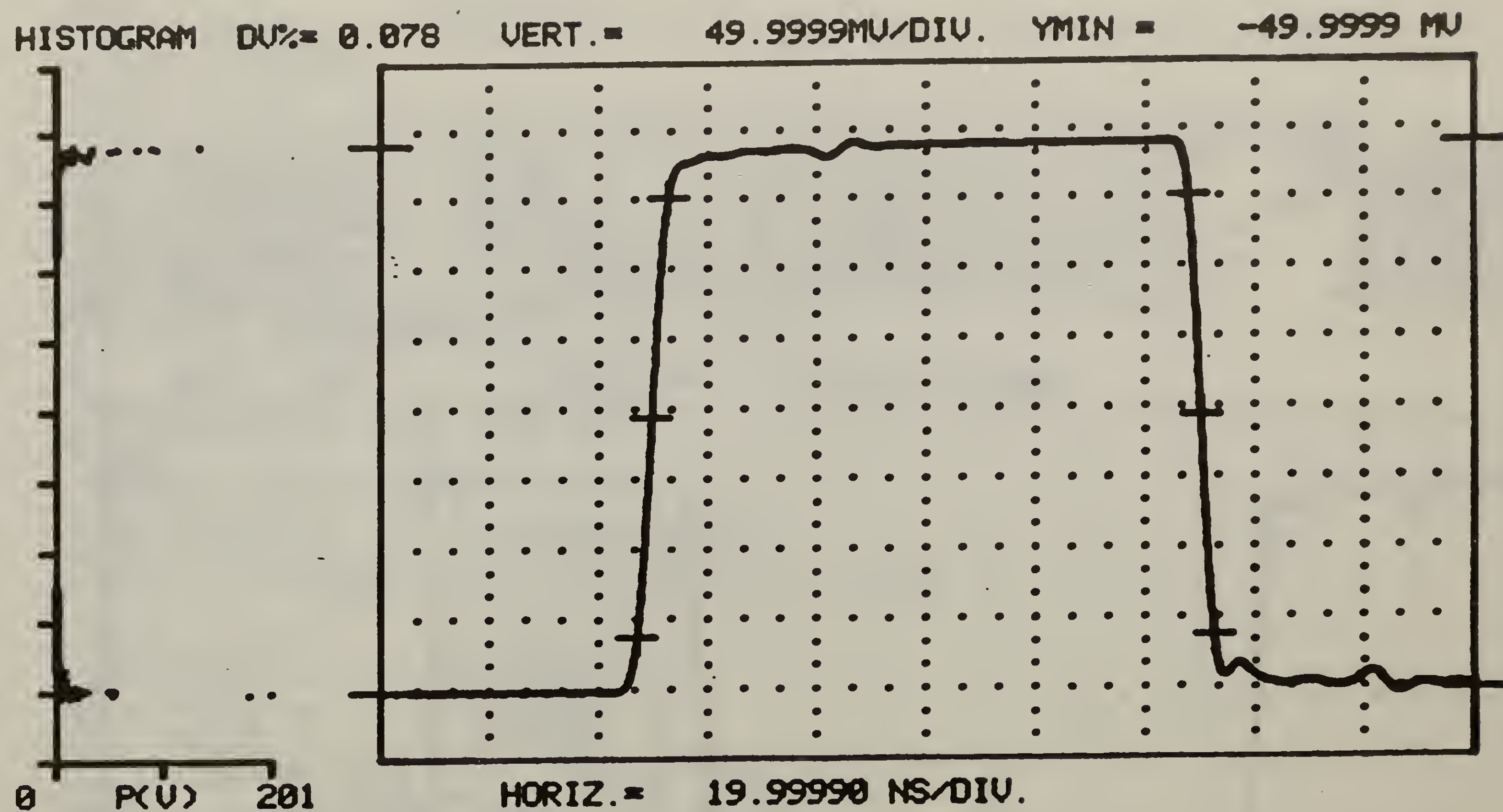


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-4.1331 MV	PULSE START TIME =	49.84190 NS
TOP MAGNITUDE =	390.9250 MV	1ST TRANSITION DURATION =	5.84106 NS
PULSE AMPLITUDE =	395.0580 MV	2ED TRANSITION DURATION =	4.82585 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	100.32100 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	150.16300 NS

PULSE---DIRECT TO SAMPLER +F---MIN-MAX WLG 6/26/81

Figure 20a. 100 ns, 400 mV pulse with parameters determined from MIN-MAX definition.

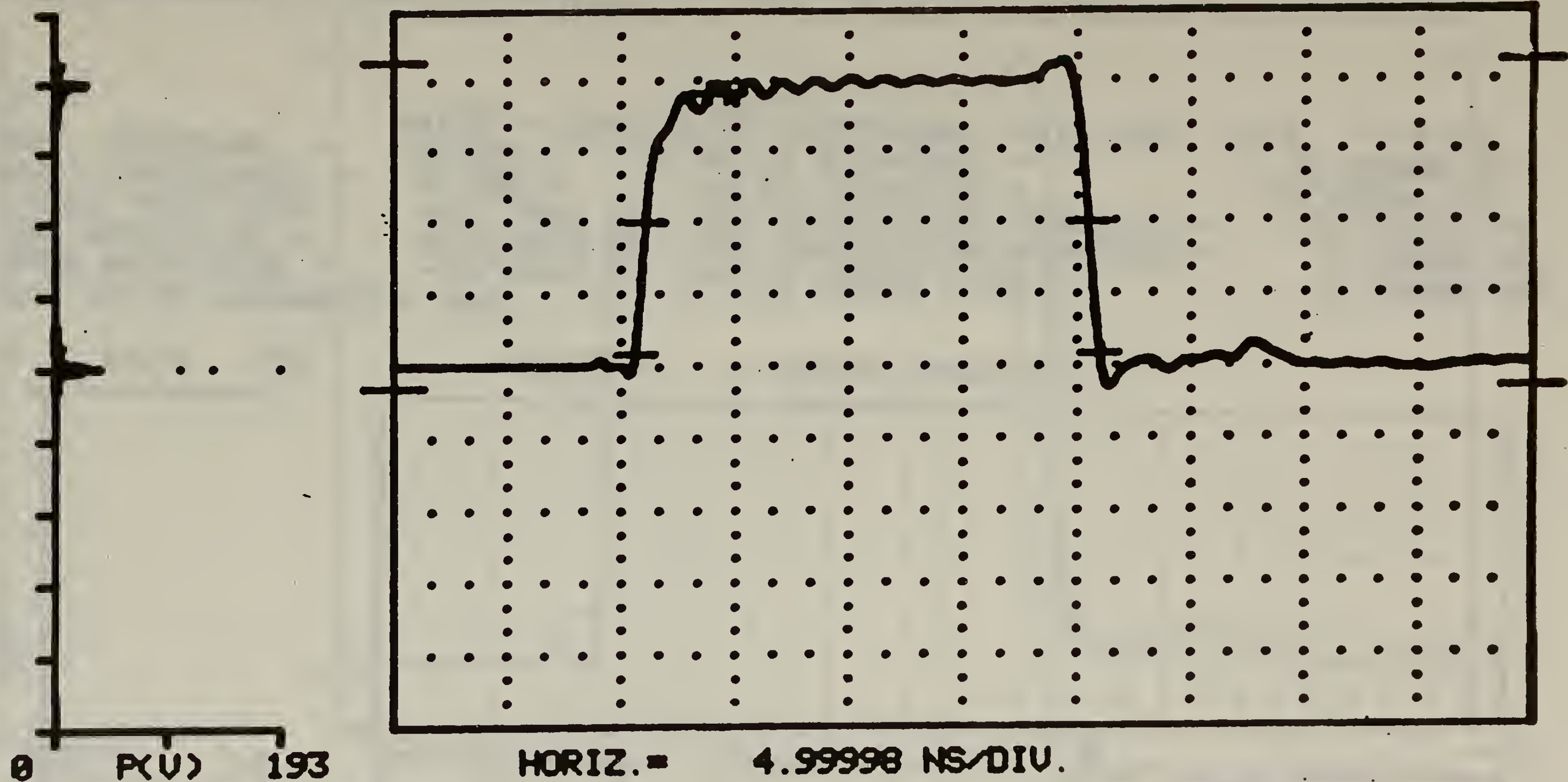


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-2.1270 MV	PULSE START TIME =	49.85000 NS
TOP MAGNITUDE =	389.8450 MV	1ST TRANSITION DURATION =	5.76568 NS
PULSE AMPLITUDE =	391.9720 MV	2ED TRANSITION DURATION =	4.74874 NS
MAX. UNDERSHOOT =	0.511 %	PULSE DURATION =	100.30900 NS
MAX. OVERSHOOT =	0.275 %	PULSE STOPTIME =	150.15900 NS

PULSE---DIRECT TO SAMPLER +F---HISTOGRAM WLG 6/26/81

Figure 20b. 100 ns, 400 mV pulse with parameters determined from HISTOGRAM definition.



THE PULSE PARAMETERS ARE:
BASE MAGNITUDE = -30.7511 MV PULSE START TIME = 11.09520 NS
TOP MAGNITUDE = 428.0690 MV 1ST TRANSITION DURATION = 3.26689 NS
PULSE AMPLITUDE = 458.8200 MV 2ED TRANSITION DURATION = 16 39330 NS
MAX. UNDERSHOOT = 0.000 % PULSE DURATION = 19.40390 NS
MAX. OVERSHOOT = 0.000 % PULSE STOPTIME = 30.49910 NS
PULSE---DIRECT TO SAMPLER---MIN-MAX WLG 4/4/81

Figure 21. 20 ns pulse measured directly at APMS sampler through 2 m length of RG-58C 50 Ω coaxial cable (MIN-MAX definition).

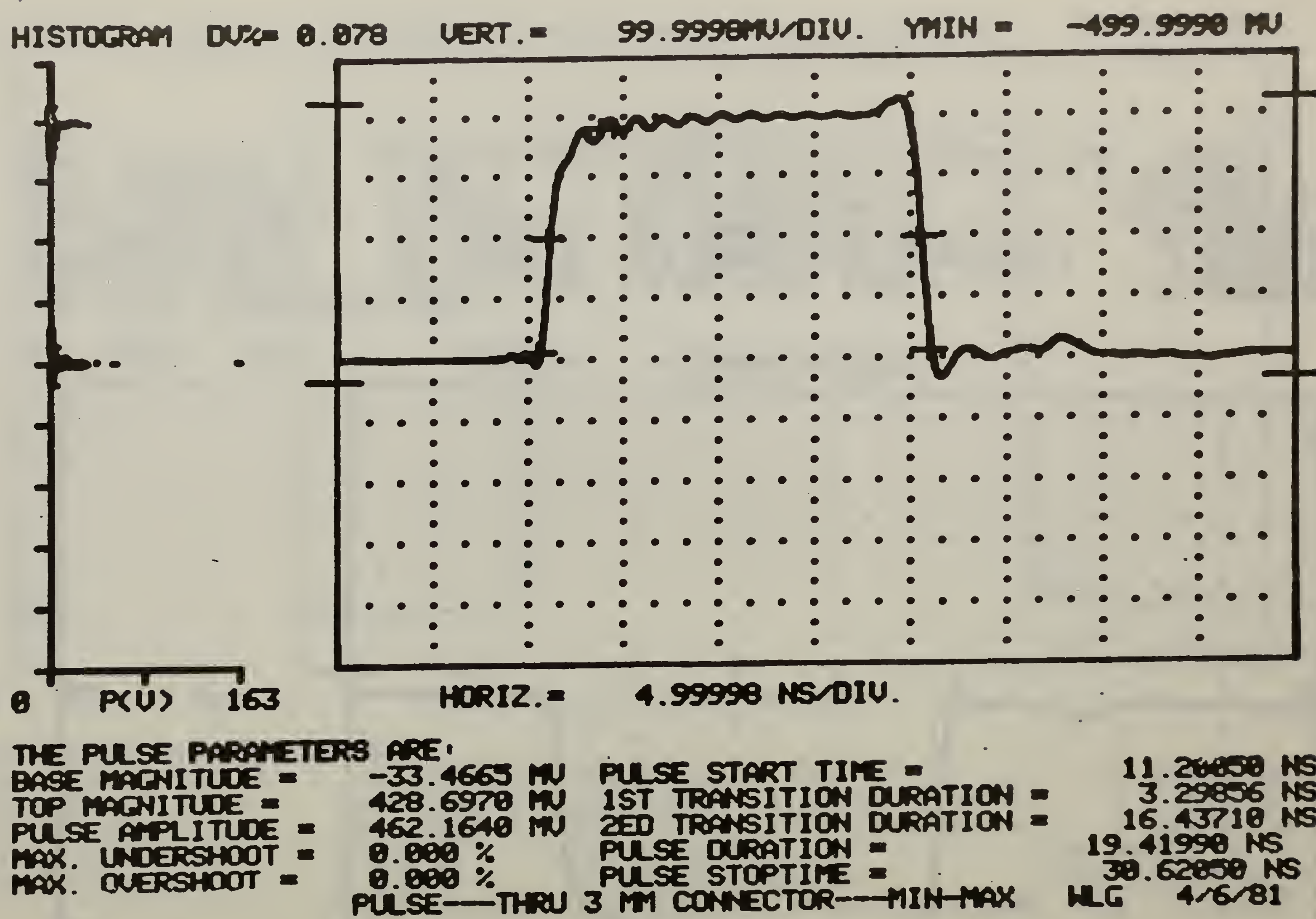
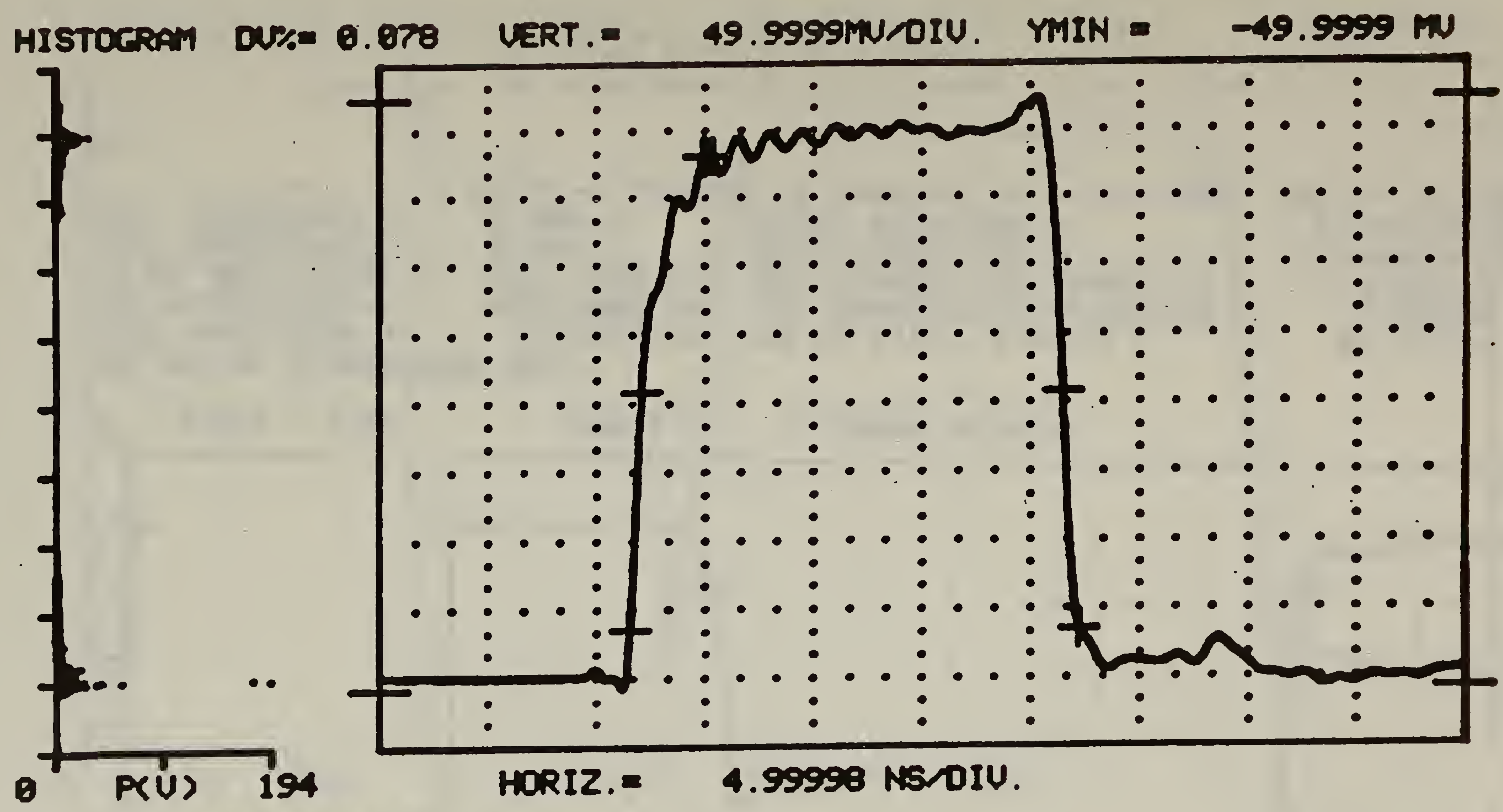


Figure 22. Same pulse as shown in figure 21 with special NBS 3 mm SMA/twin lead adapter inserted at APMS sampler interface plane.

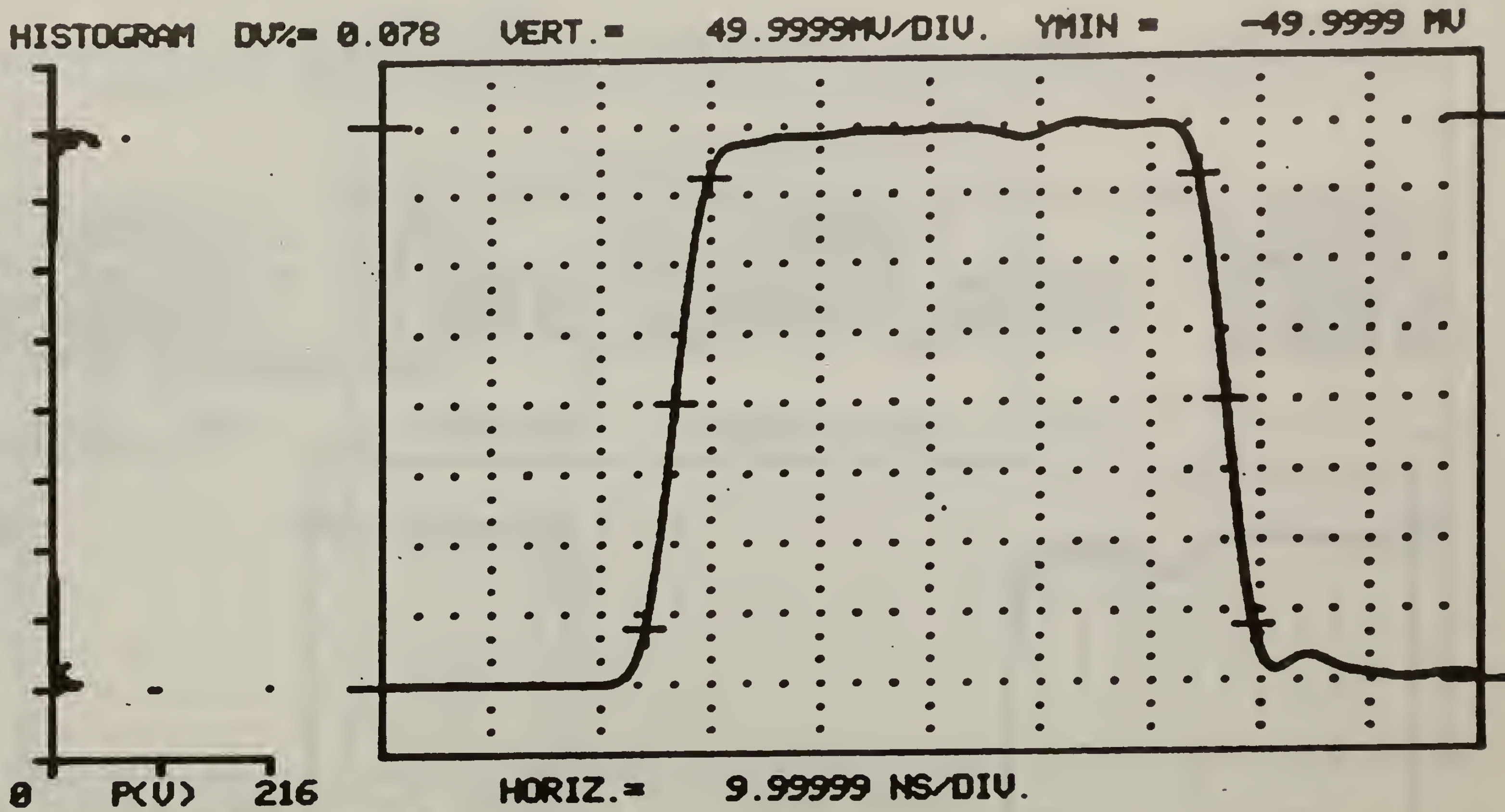


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-7.8021 MV	PULSE START TIME =	12.09410 NS
TOP MAGNITUDE =	424.2080 MV	1ST TRANSITION DURATION =	3.37761 NS
PULSE AMPLITUDE =	432.0100 MV	2ED TRANSITION DURATION =	16.89670 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	19.38070 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	31.47490 NS

PULSE---THRU ITT CONNECTOR---MIN-MAX WLG 4/6/81

Figure 23. Same pulse as shown in figure 22 with EQUATE PIU connector and twin lead/BNC adapter inserted at 3 mm SMA/ twin lead adapter interface plane.



THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-0.6812 MV	PULSE START TIME =	26.97730 NS
TOP MAGNITUDE =	403.0980 MV	1ST TRANSITION DURATION =	5.755[illegible]8 NS
PULSE AMPLITUDE =	403.7790 MV	2ED TRANSITION DURATION =	5.85453 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	50.08028 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	77.05760 NS

PULSE——DIRECT TO SAMPLER +F——MIN-MAX WLG 4/7/81

Figure 24a. NBS pulse source 50 ns pulse direct to APMS sampler with 5 ns NBS filter (MIN-MAX definition).

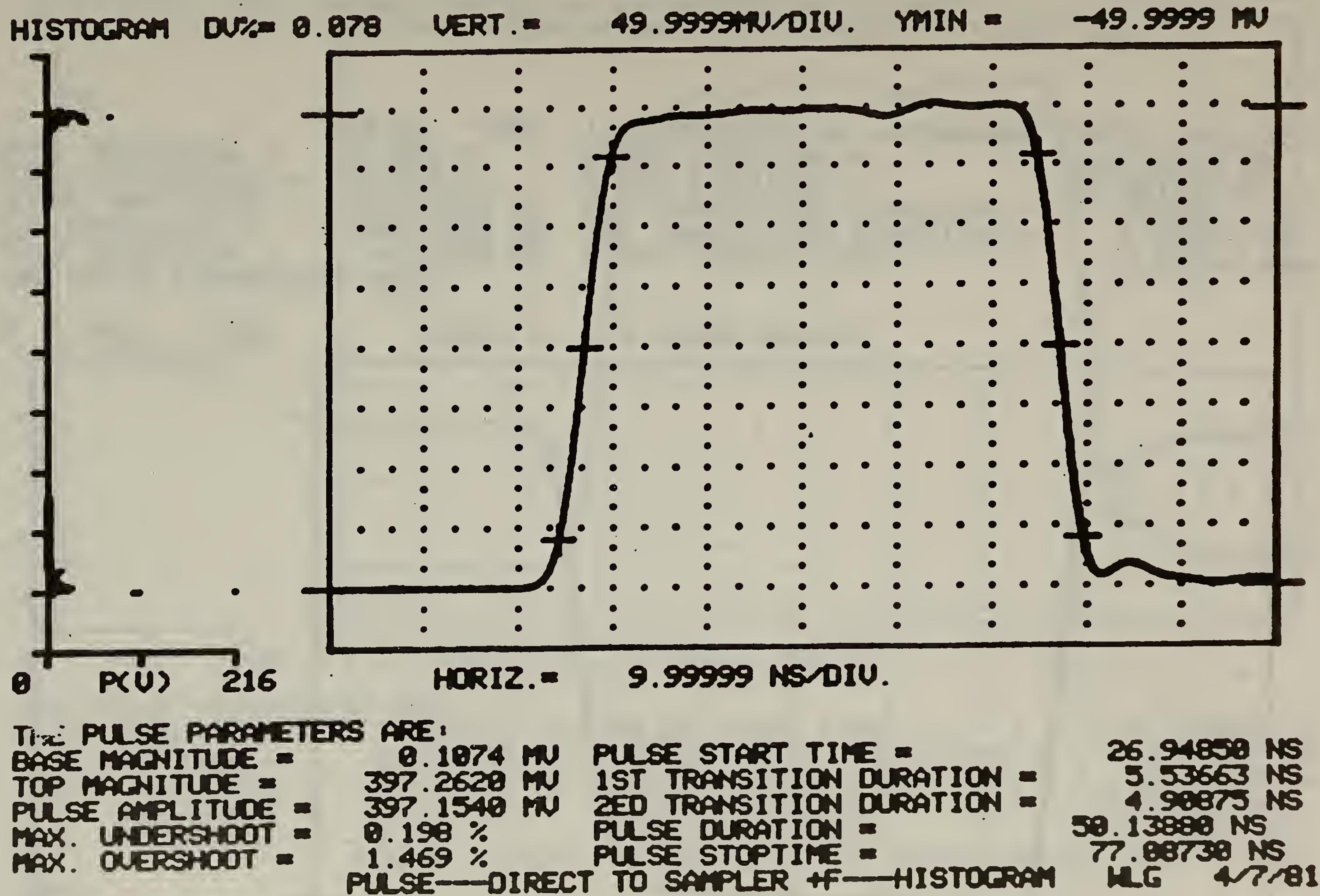


Figure 24b. NBS pulse source 50 ns pulse direct to APMS sampler with 5 ns NBS filter (HISTOGRAM definition).

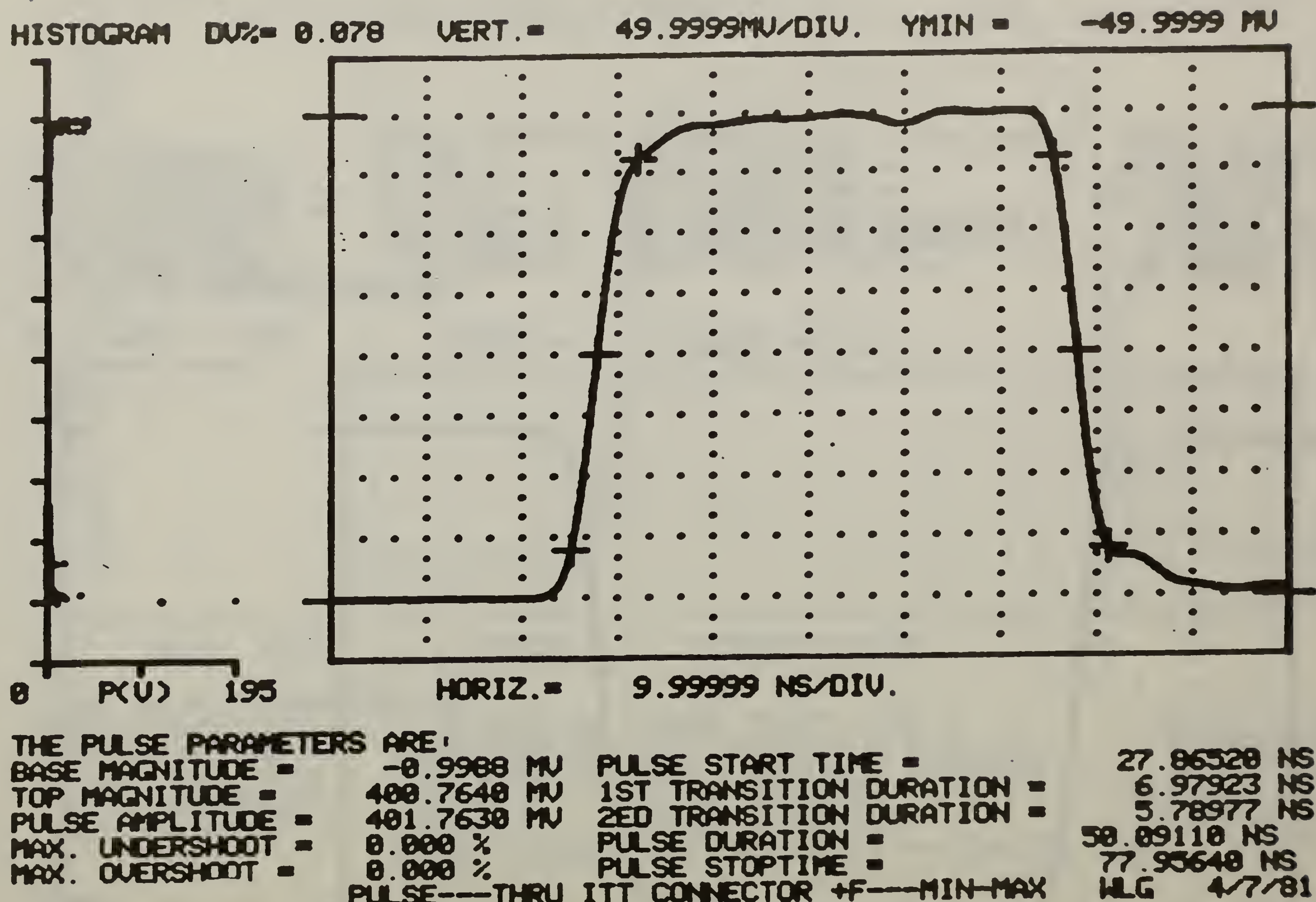


Figure 25a. Same pulse as shown in figure 24a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).

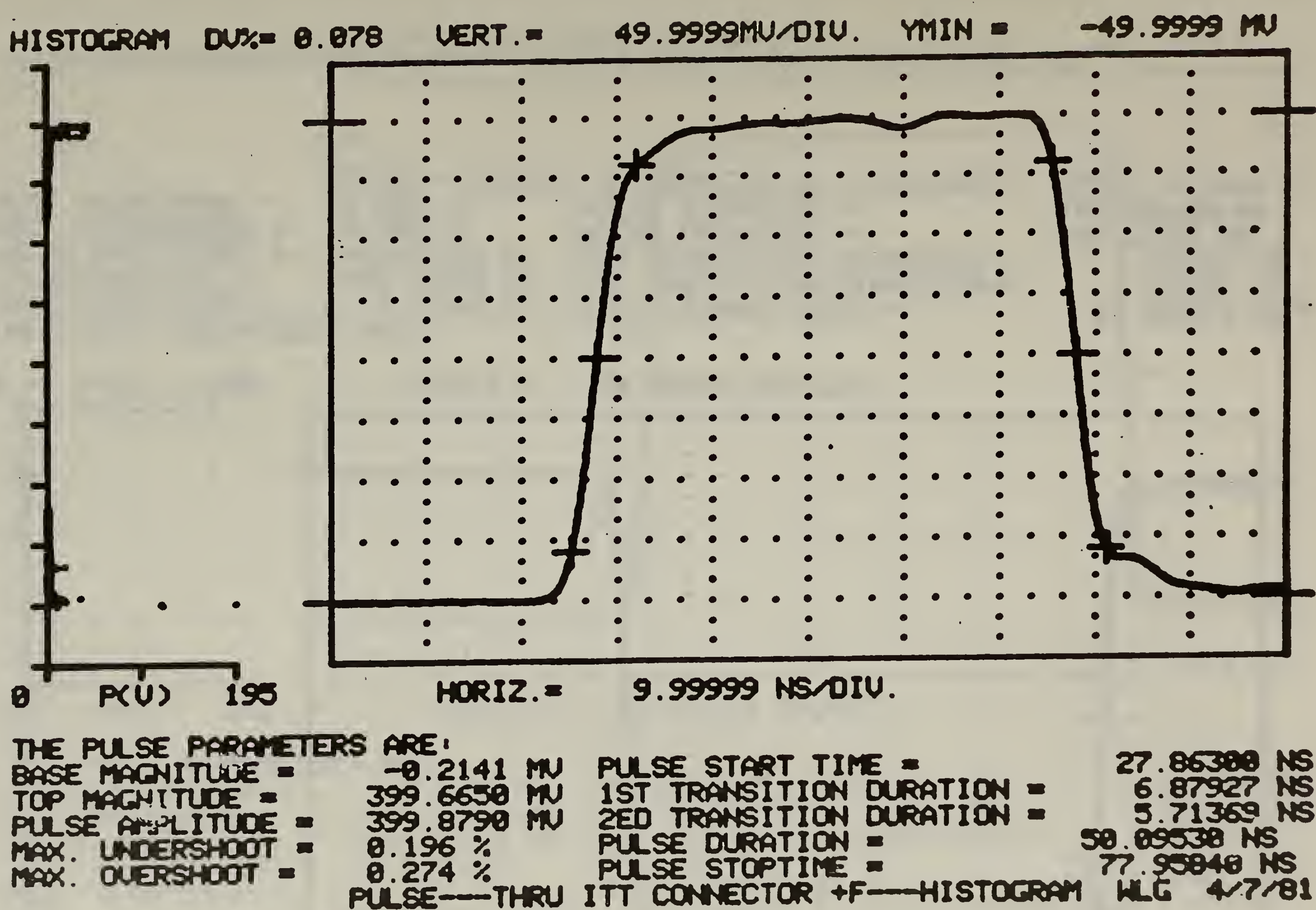


Figure 25b. Same pulse as shown in figure 24b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).

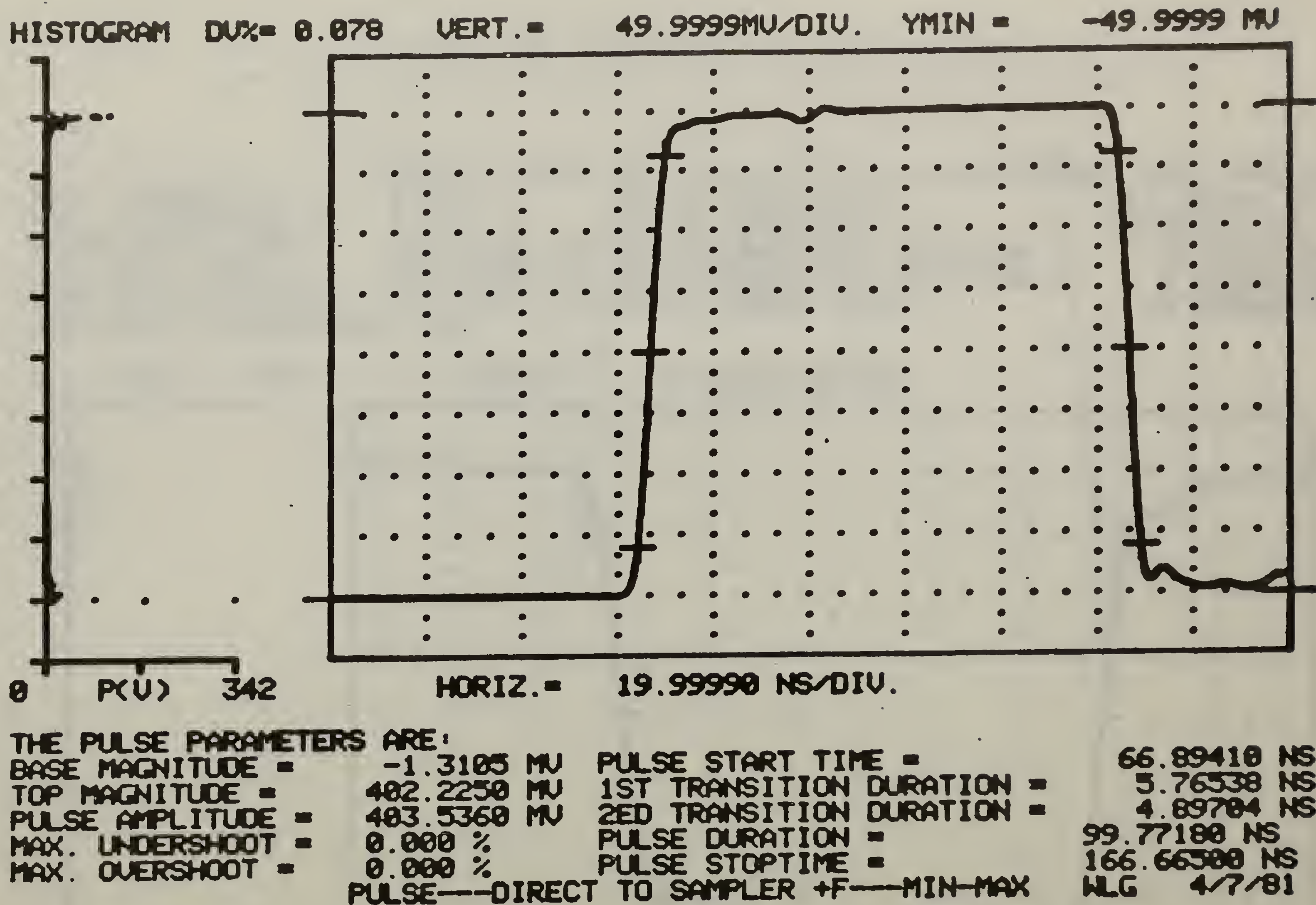


Figure 26a. NBS pulse source 100 ns pulse direct to APMS sampler with 5 ns NBS filter (MIN-MAX definition).

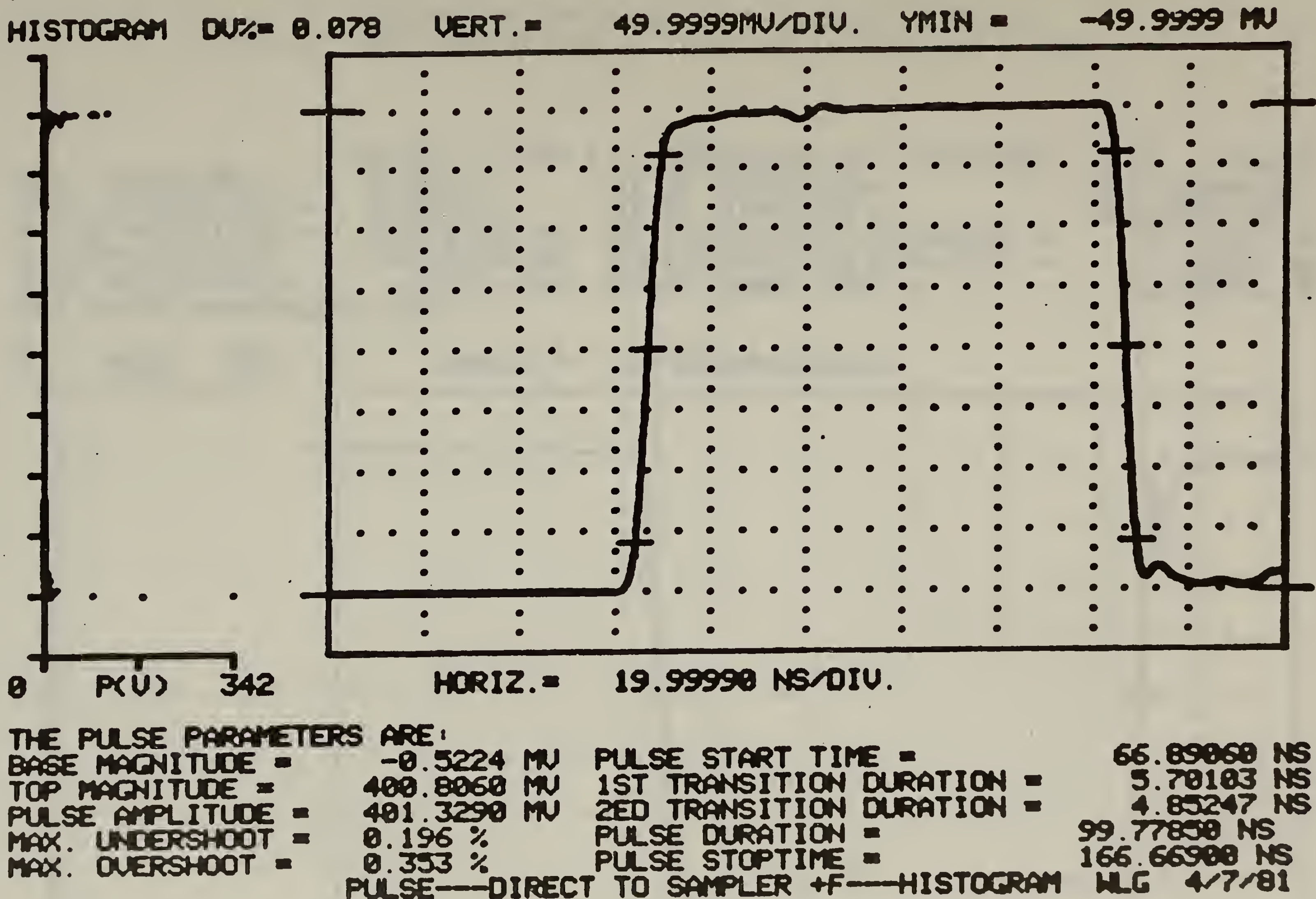
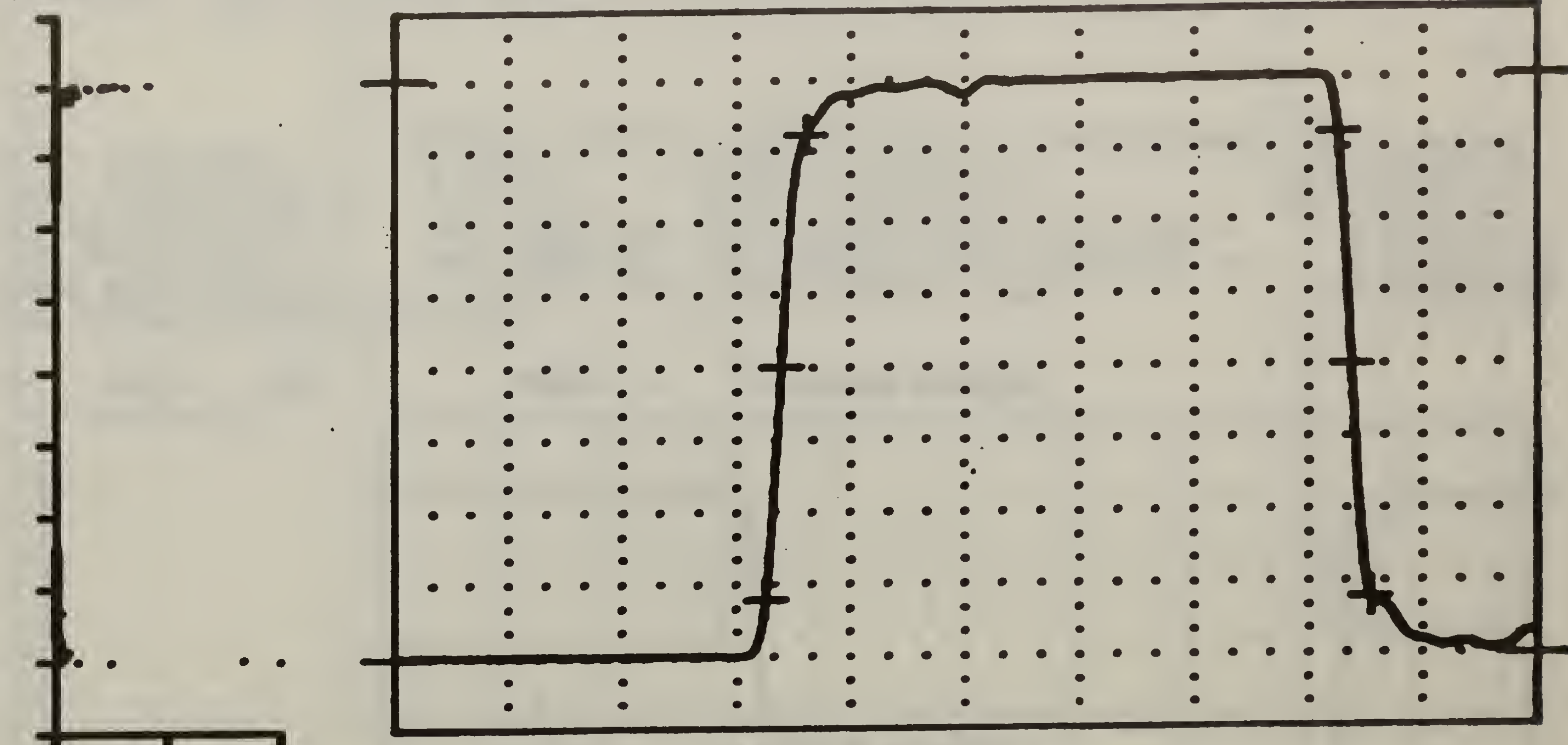


Figure 26b. NBS pulse source 100 ns pulse direct to APMS sampler with 5 ns NBS filter (HISTOGRAM definition).

HISTOGRAM DV%= 0.078 VERT.= 49.9999MV/DIV. YMIN = -49.9999 MV

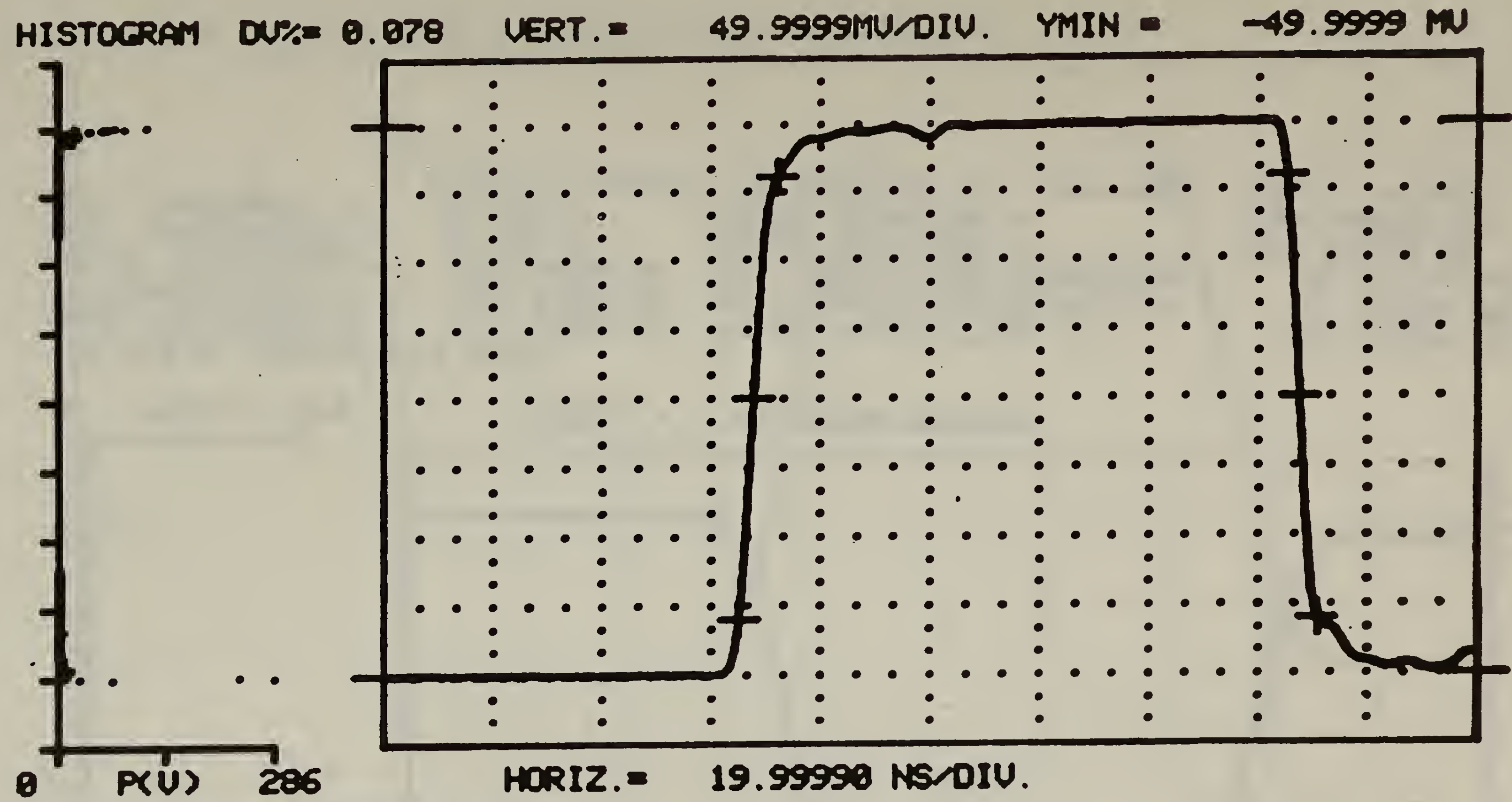


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-0.8227 MV	PULSE START TIME =	67.83940 NS
TOP MAGNITUDE =	401.6920 MV	1ST TRANSITION DURATION =	7.12359 NS
PULSE AMPLITUDE =	402.5150 MV	2ED TRANSITION DURATION =	5.71153 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	99.73440 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	167.57380 NS

PULSE---THRU ITT CONNECTOR +F---MIN-MAX WLG 4/7/81

Figure 27a. Same pulse as shown in figure 26a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).

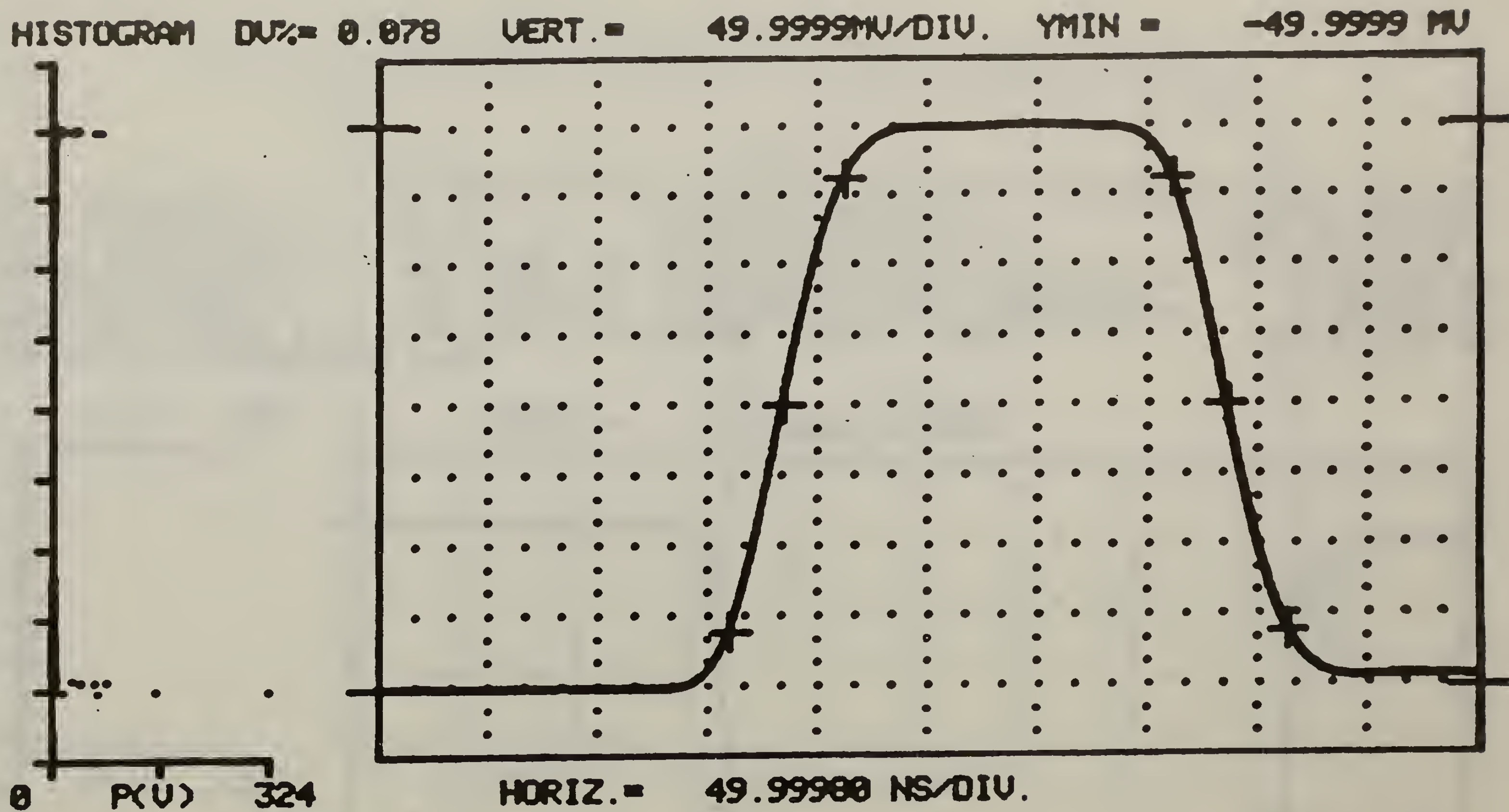


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-0.3510 MV	PULSE START TIME =	67.83740 NS
TOP MAGNITUDE =	400.9060 MV	1ST TRANSITION DURATION =	7.02302 NS
PULSE AMPLITUDE =	401.2560 MV	2ED TRANSITION DURATION =	5.66424 NS
MAX. UNDERSHOOT =	0.117 %	PULSE DURATION =	99.73870 NS
MAX. OVERSHOOT =	0.196 %	PULSE STOPTIME =	167.57600 NS

PULSE---THRU ITT CONNECTOR +F---HISTOGRAM WLG 4/7/81

Figure 27b. Same pulse as shown in figure 26b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).



THE PULSE PARAMETERS ARE:
BASE MAGNITUDE = -1.9502 MV
TOP MAGNITUDE = 401.9380 MV
PULSE AMPLITUDE = 403.8880 MV
MAX. UNDERSHOOT = 0.000 %
MAX. OVERSHOOT = 0.000 %

PULSE START TIME = 184.26500 NS
1ST TRANSITION DURATION = 51.72200 NS
2ED TRANSITION DURATION = 52.93110 NS
PULSE DURATION = 200.14200 NS
PULSE STOPTIME = 384.40700 NS

PULSE---DIRECT TO SAMPLER +F---MIN-MAX WLG 4/8/81

Figure 28a. NBS pulse source 200 ns pulse direct to APMS sampler with 50 ns NBS filter (MIN-MAX definition).

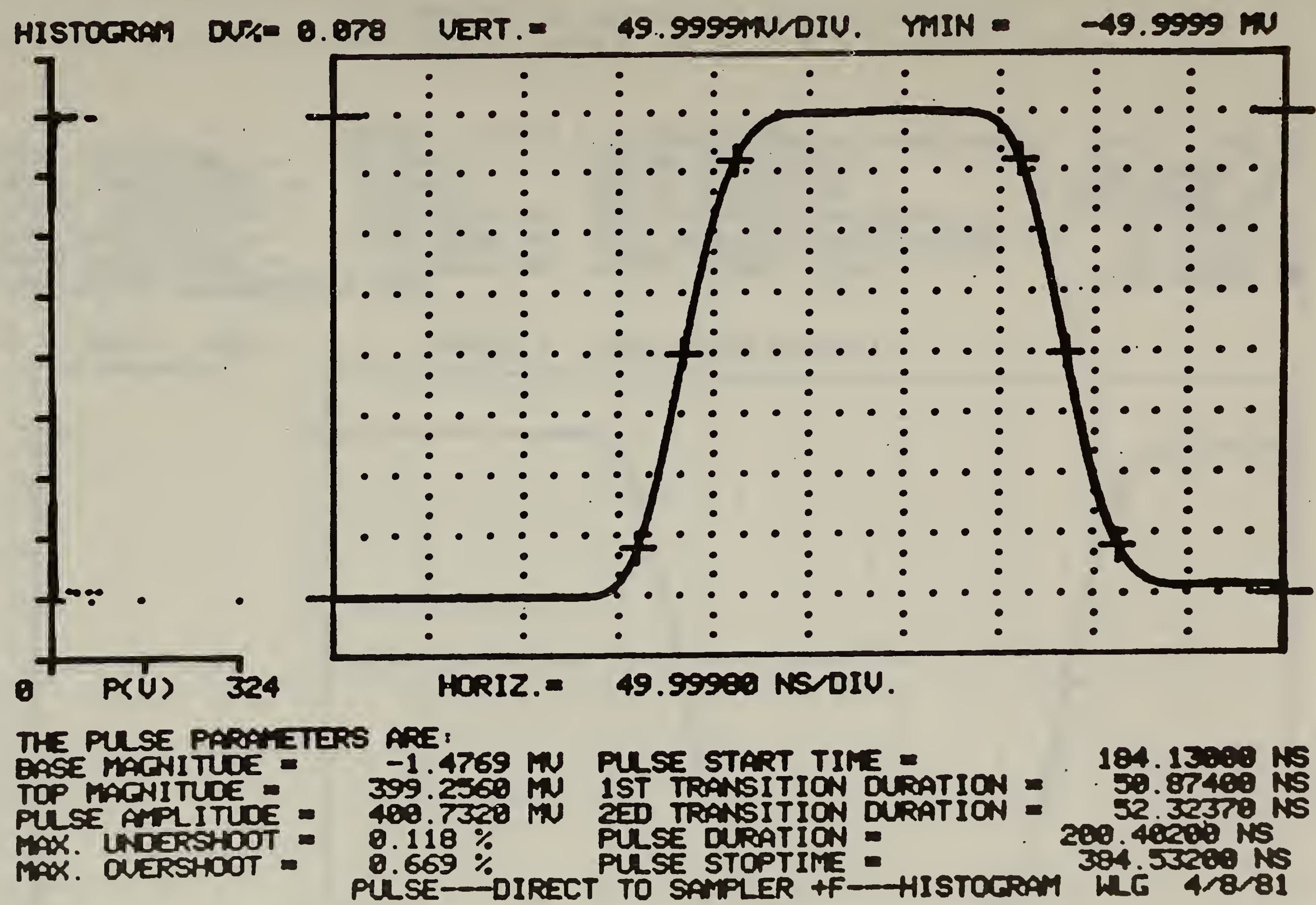


Figure 28b. NBS pulse source 200 ns pulse direct to APMS sampler with 50 ns NBS filter (HISTOGRAM definition).

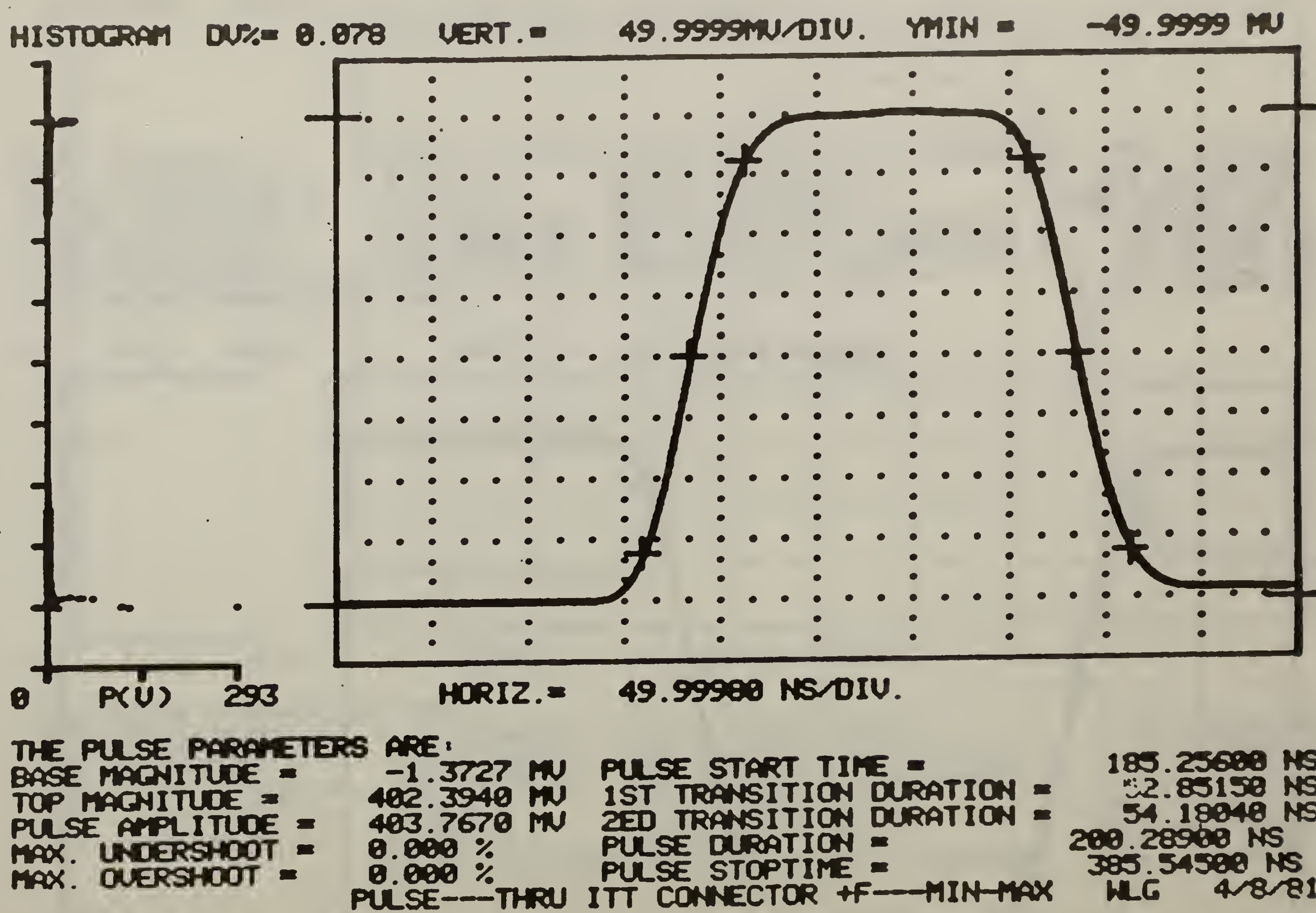


Figure 29a. Same pulse as shown in figure 28a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).

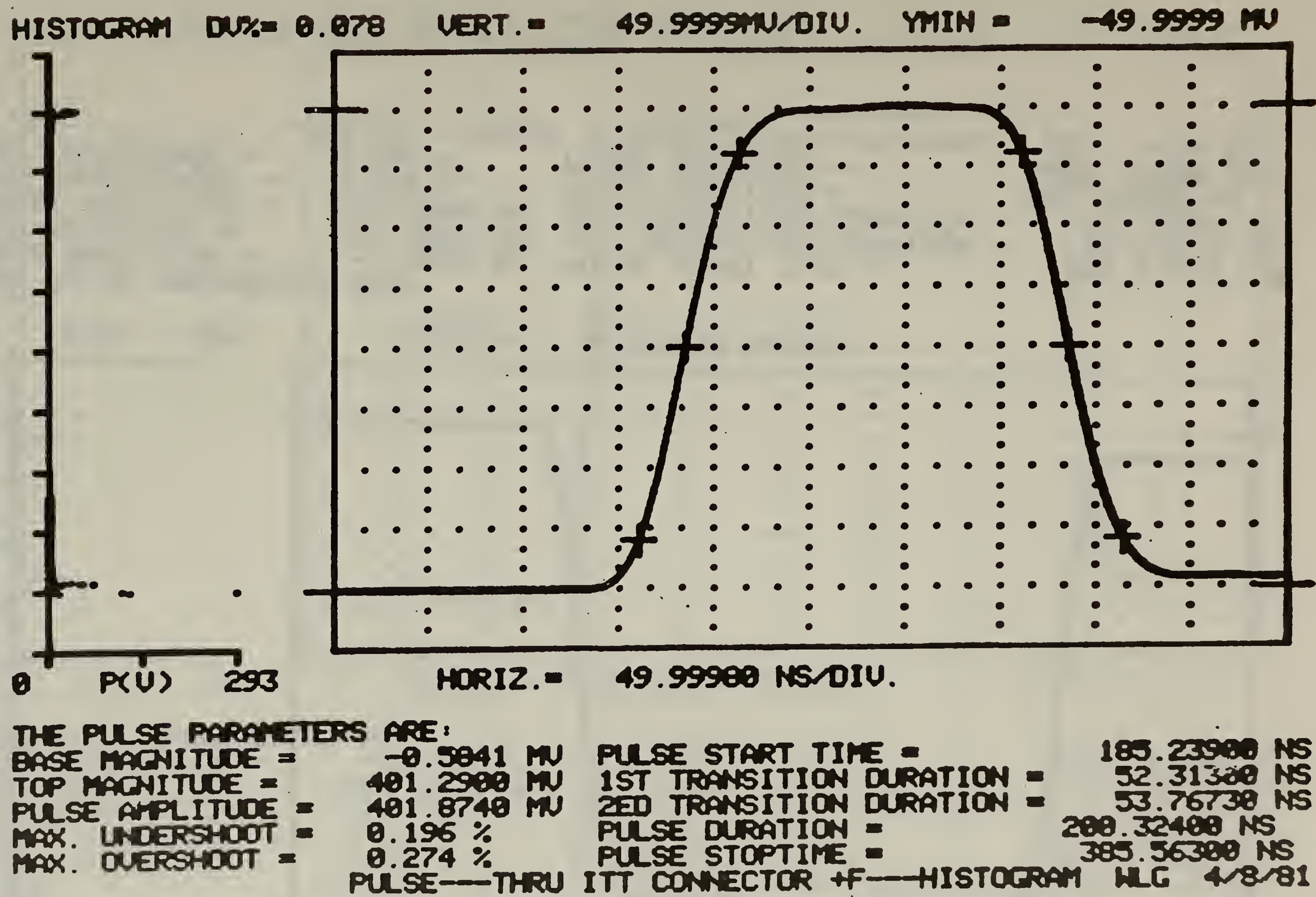
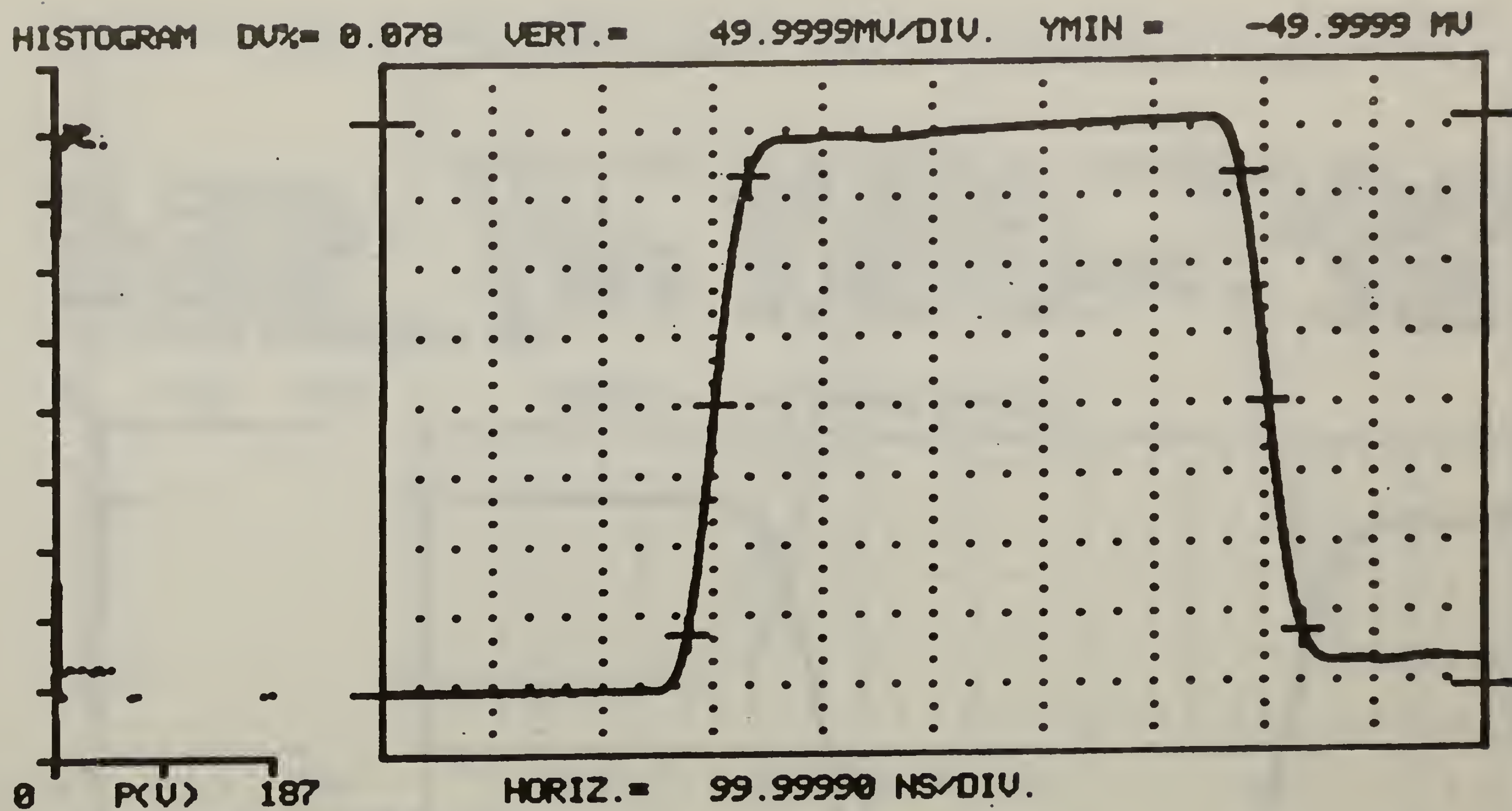


Figure 29b. Same pulse as shown in figure 28b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).

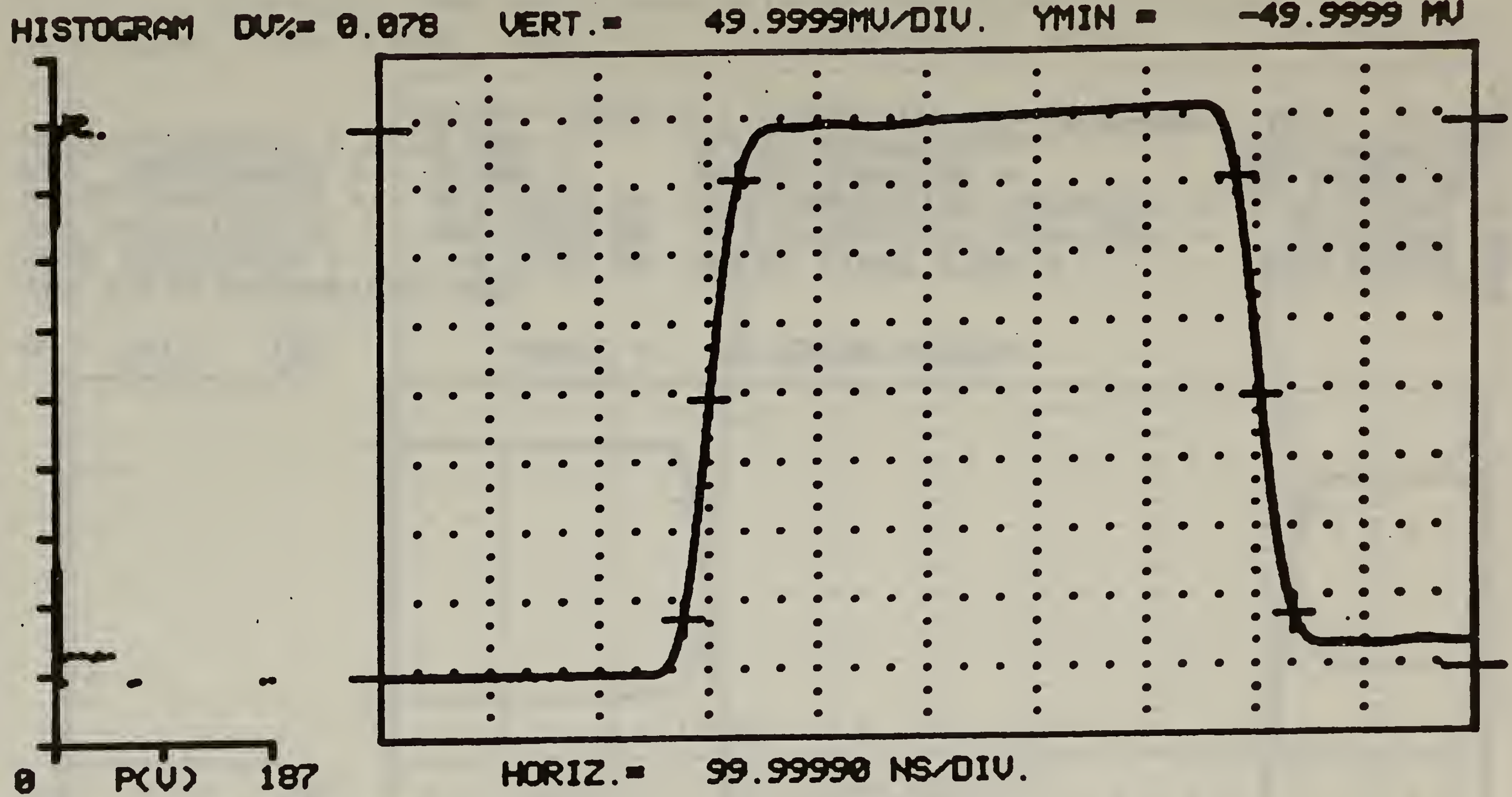


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-5.2598 MV	PULSE START TIME =	301.81[illegible]00 NS
TOP MAGNITUDE =	407.3200 MV	1ST TRANSITION DURATION =	55.50070 NS
PULSE AMPLITUDE =	412.5800 MV	2ED TRANSITION DURATION =	56.42820 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	501.87800 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	803.69200 NS

PULSE---DIRECT TO SAMPLER +F---MIN-MAX WLG 4/8/81

Figure 30a. NBS pulse source 500 ns pulse direct to APMS sampler with 50 ns NBS filter (MIN-MAX definition).

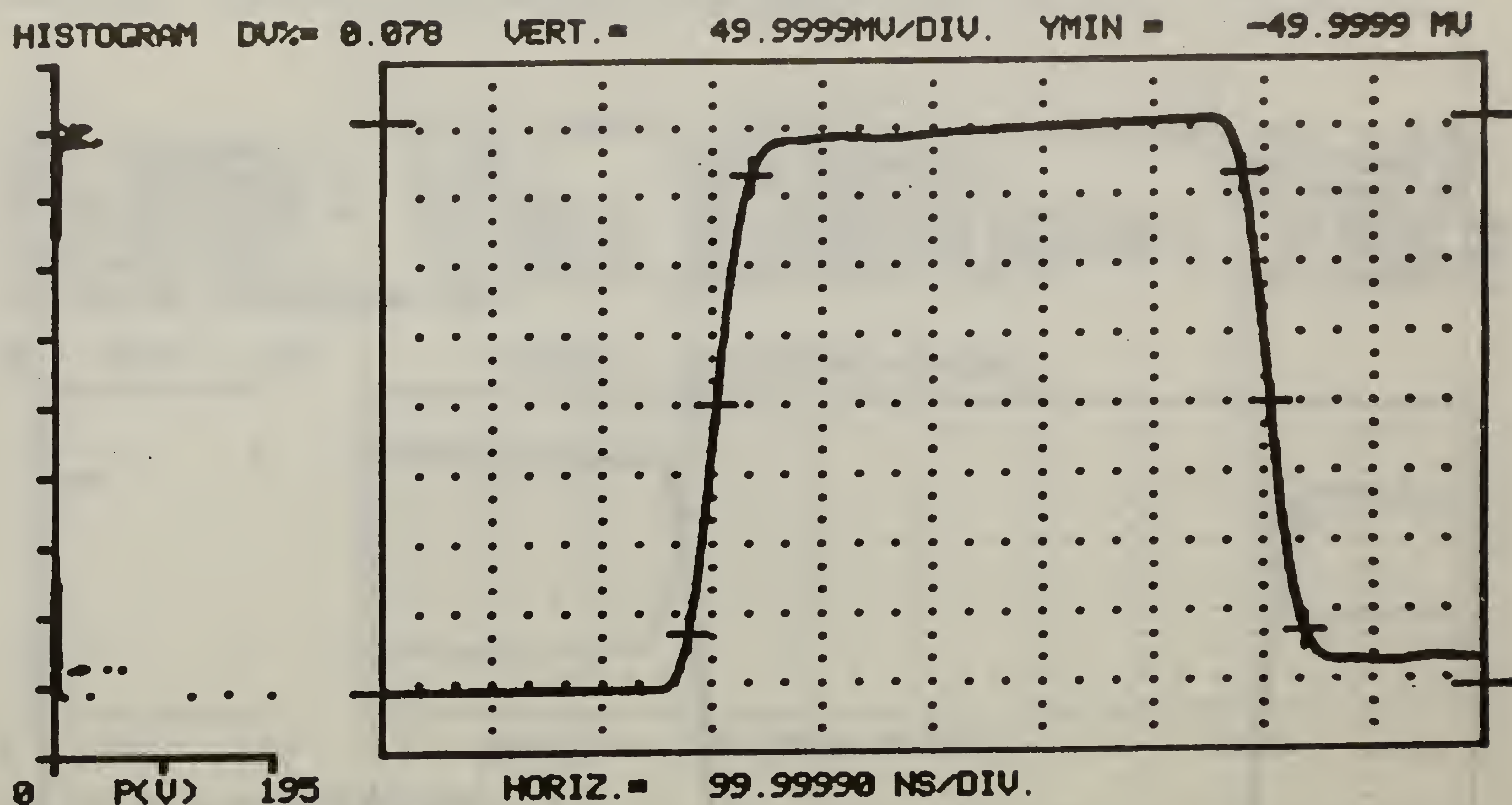


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-4.1316 MV	PULSE START TIME =	301.04400 NS
TOP MAGNITUDE =	393.6210 MV	1ST TRANSITION DURATION =	51.38720 NS
PULSE AMPLITUDE =	397.7520 MV	2ED TRANSITION DURATION =	53.85370 NS
MAX. UNDERSHOOT =	0.283 %	PULSE DURATION =	503.43400 NS
MAX. OVERSHOOT =	3.444 %	PULSE STOPTIME =	804.47800 NS

PULSE---DIRECT TO SAMPLER +F---HISTOGRAM WLG 4/8/81

Figure 30b. NBS pulse source 500 ns pulse direct to APMS sampler with 50 ns NBS filter (HISTOGRAM definition).



THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-6.4139 MV	PULSE START TIME =	303.82400 NS
TOP MAGNITUDE =	405.7580 MV	1ST TRANSITION DURATION =	56.91380 NS
PULSE AMPLITUDE =	412.1720 MV	2ED TRANSITION DURATION =	57.52880 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	501.84100 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	805.66500 NS

PULSE---THRU ITT CONNECTOR +F---MIN-MAX WLG 4/8/81

Figure 31a. Same pulse as shown in figure 30a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).

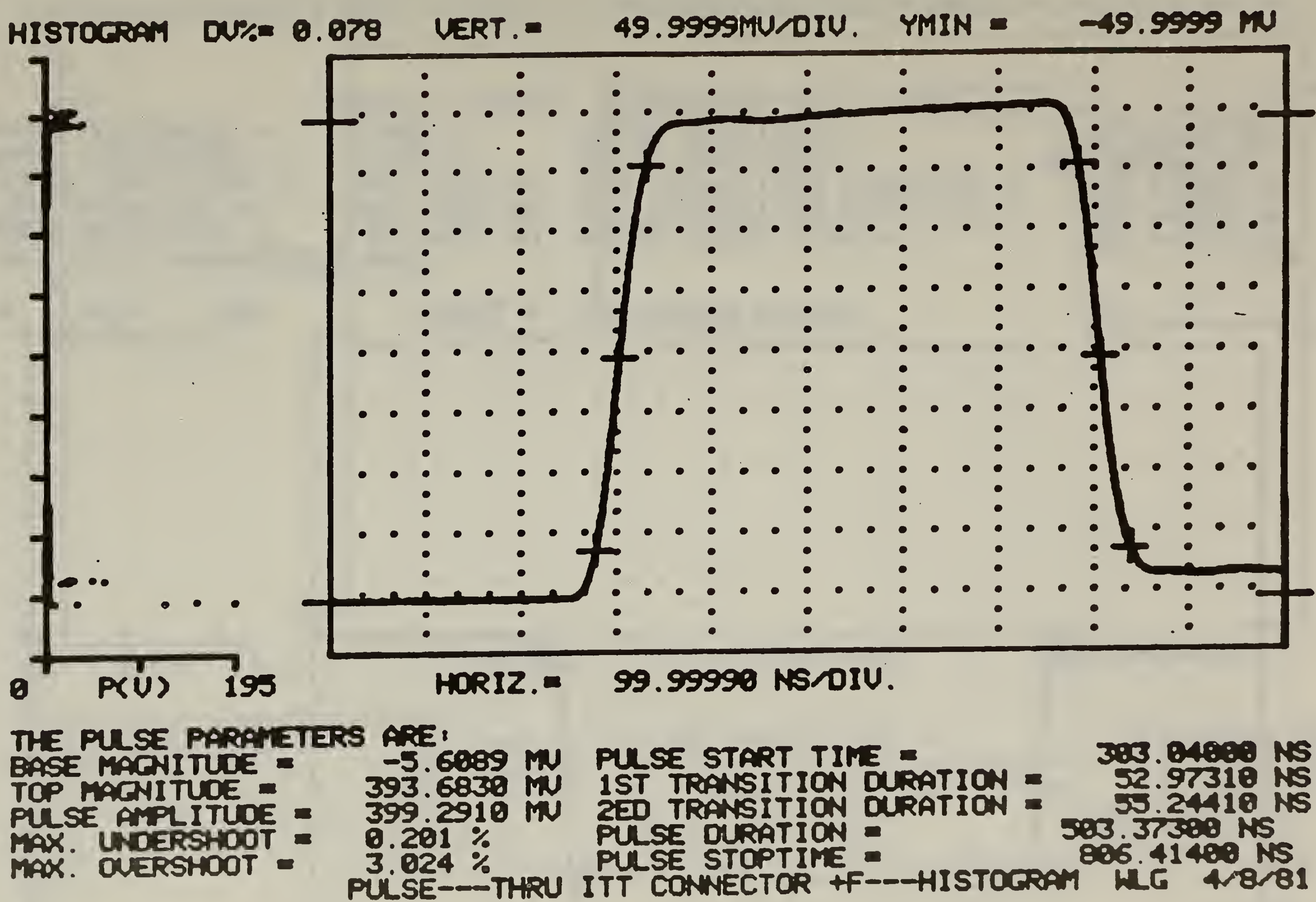


Figure 31b. Same pulse as shown in figure 30b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).

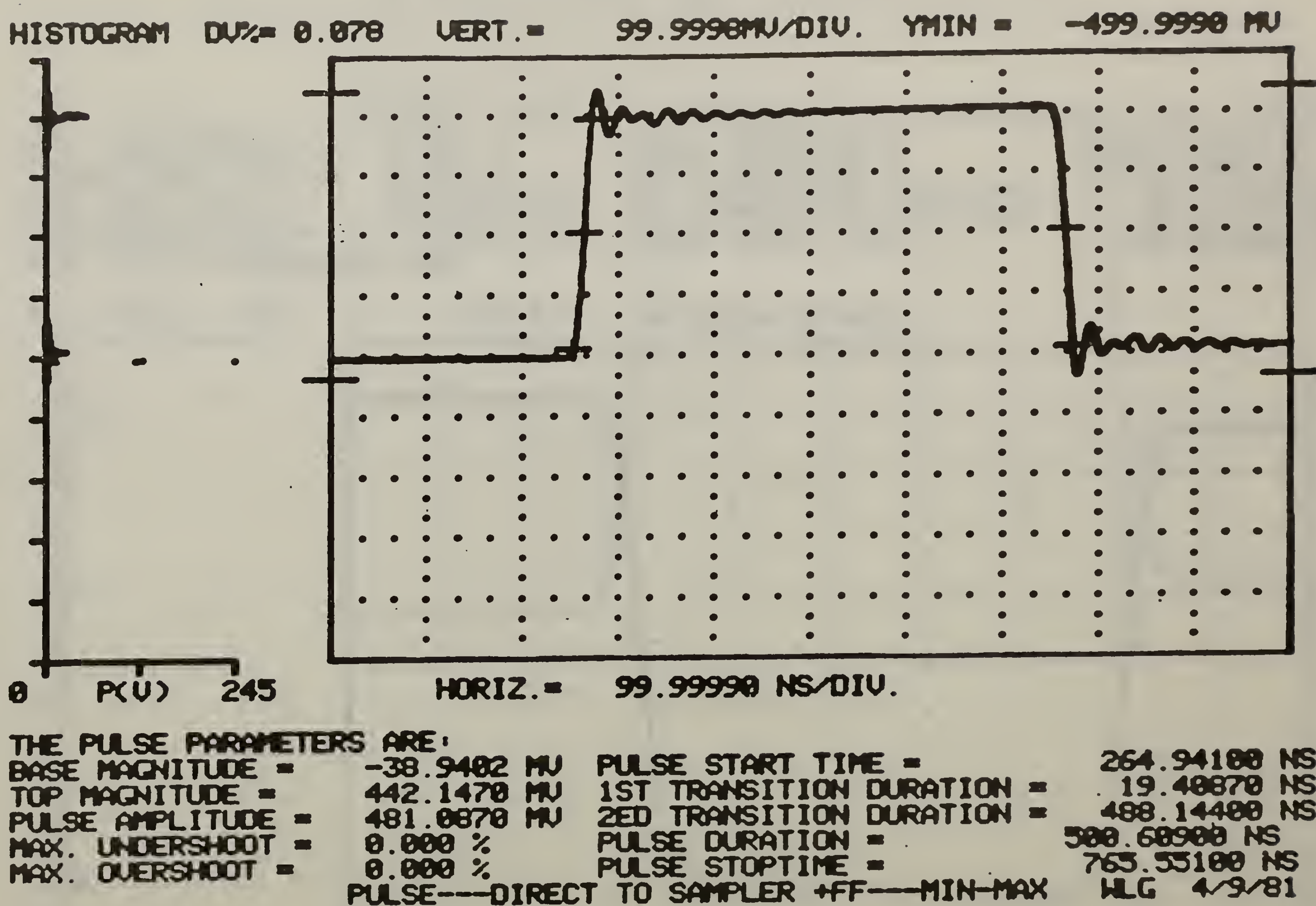


Figure 32a. NBS pulse source 500 ns pulse direct to APMS sampler with 5 ns and sharp-cutoff NBS filters (MIN-MAX definition).

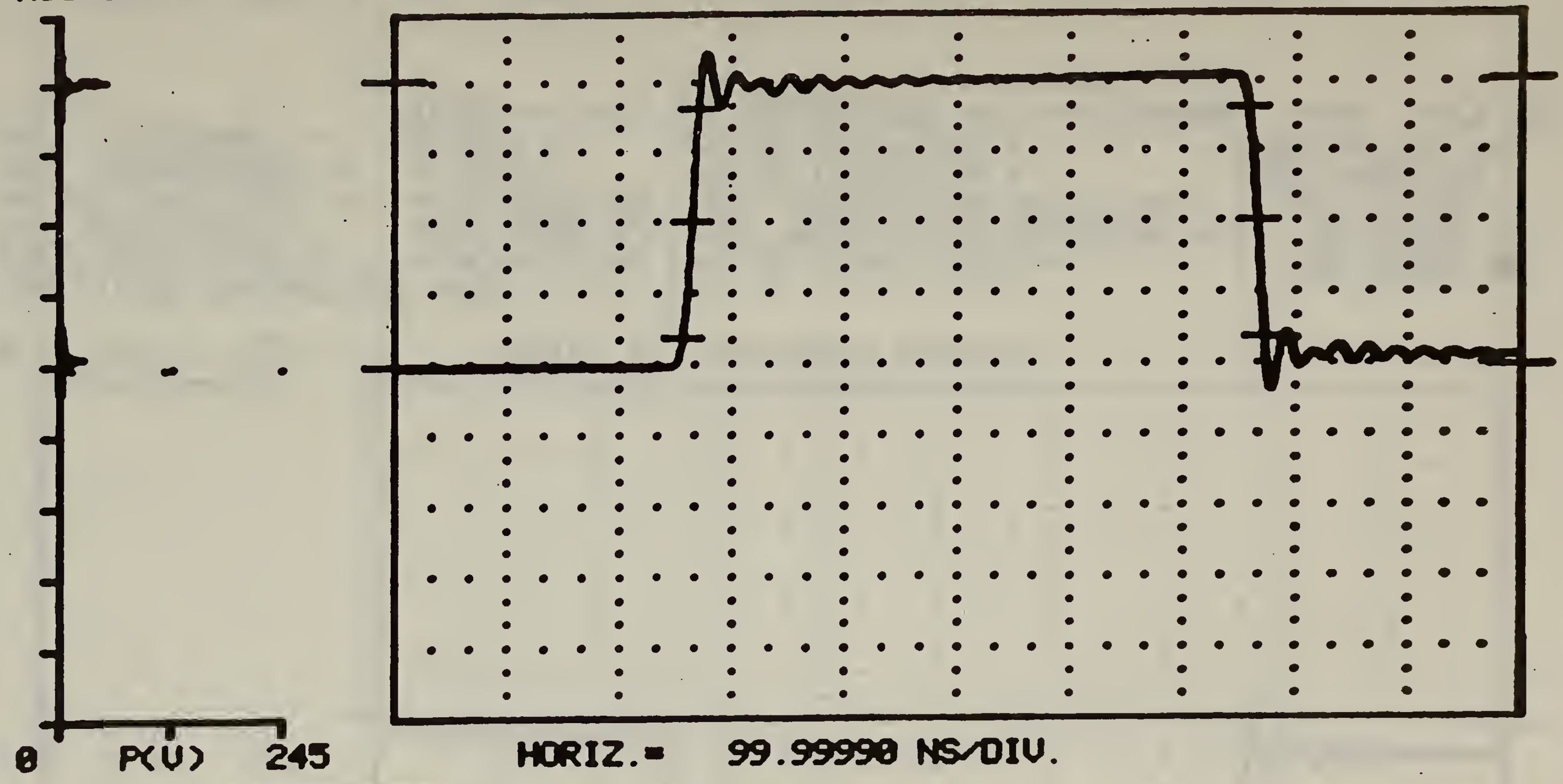
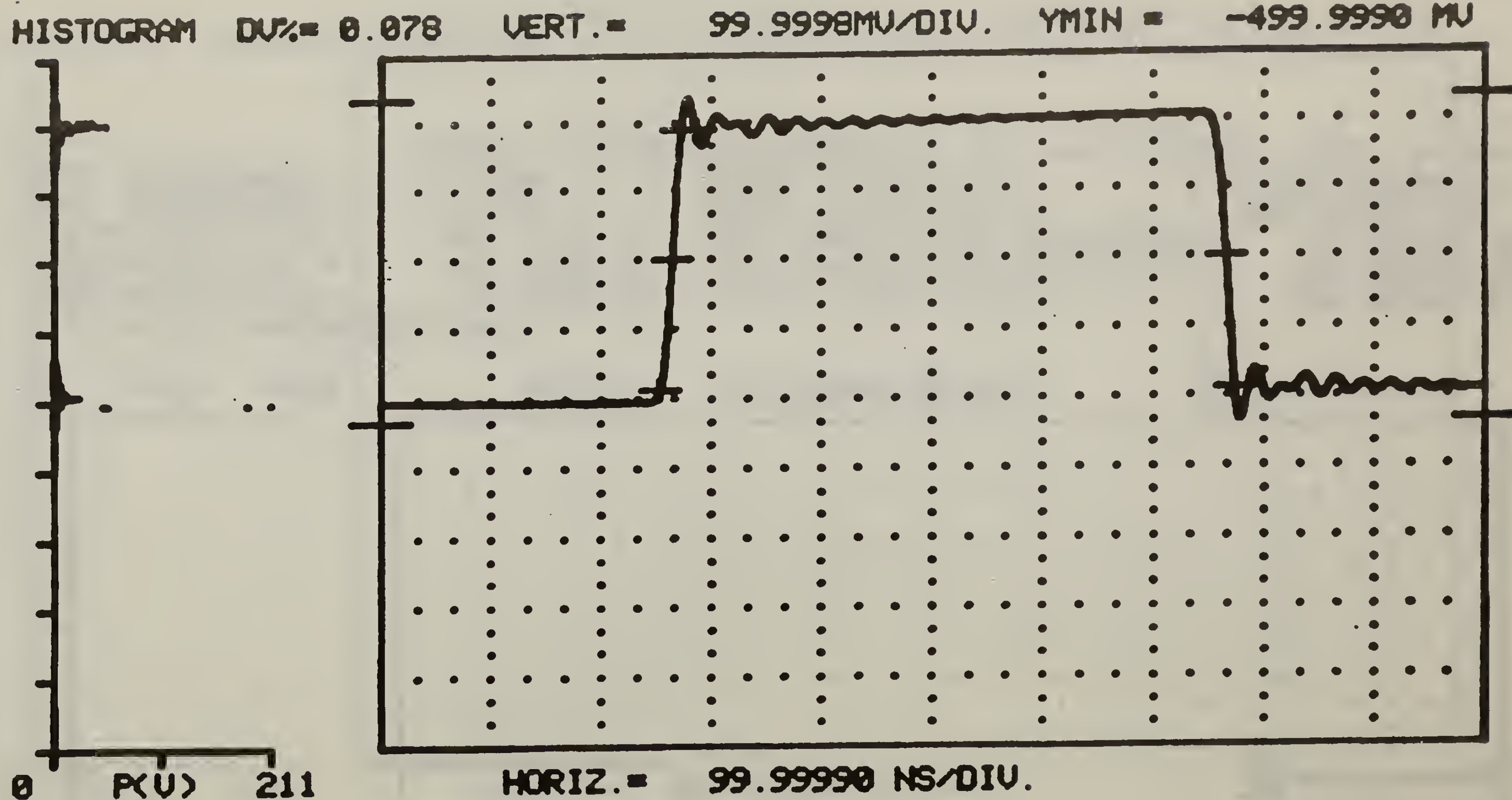


Figure 32b. NBS pulse source 500 ns pulse direct to APMS sampler with 5 ns and sharp-cutoff NBS filters (HISTOGRAM definition).



THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-34.6427 MV	PULSE START TIME =	265.22000 NS
TOP MAGNITUDE =	436.4500 MV	1ST TRANSITION DURATION =	18.92330 NS
PULSE AMPLITUDE =	471.0930 MV	2ED TRANSITION DURATION =	487 71300 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	500.64900 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	765.87700 NS

PULSE---THRU ITT CONNECTOR +FF---MIN-MAX WLG 4/9/81

Figure 33a. Same pulse as shown in figure 32a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).

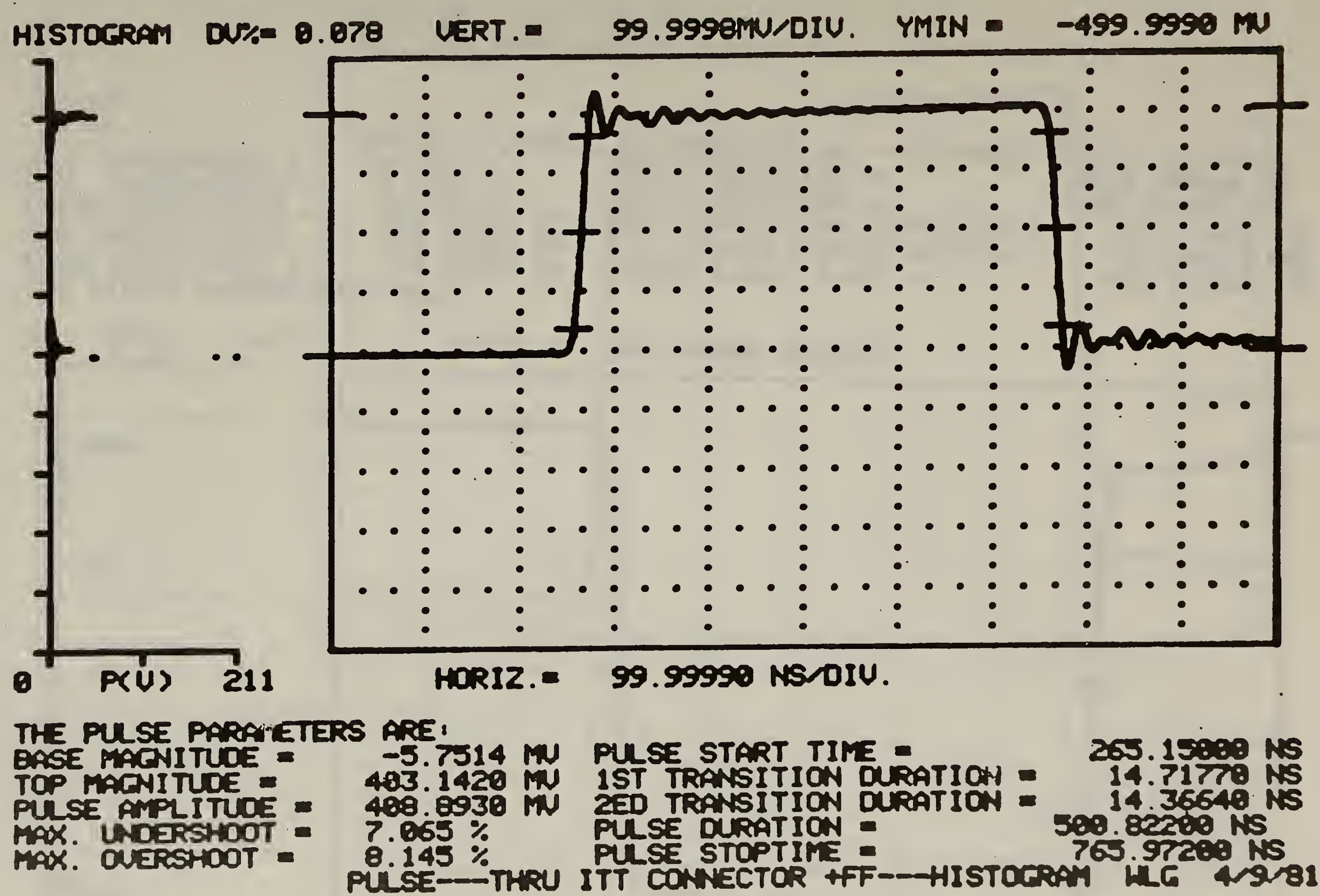


Figure 33b. Same pulse as shown in figure 32b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).

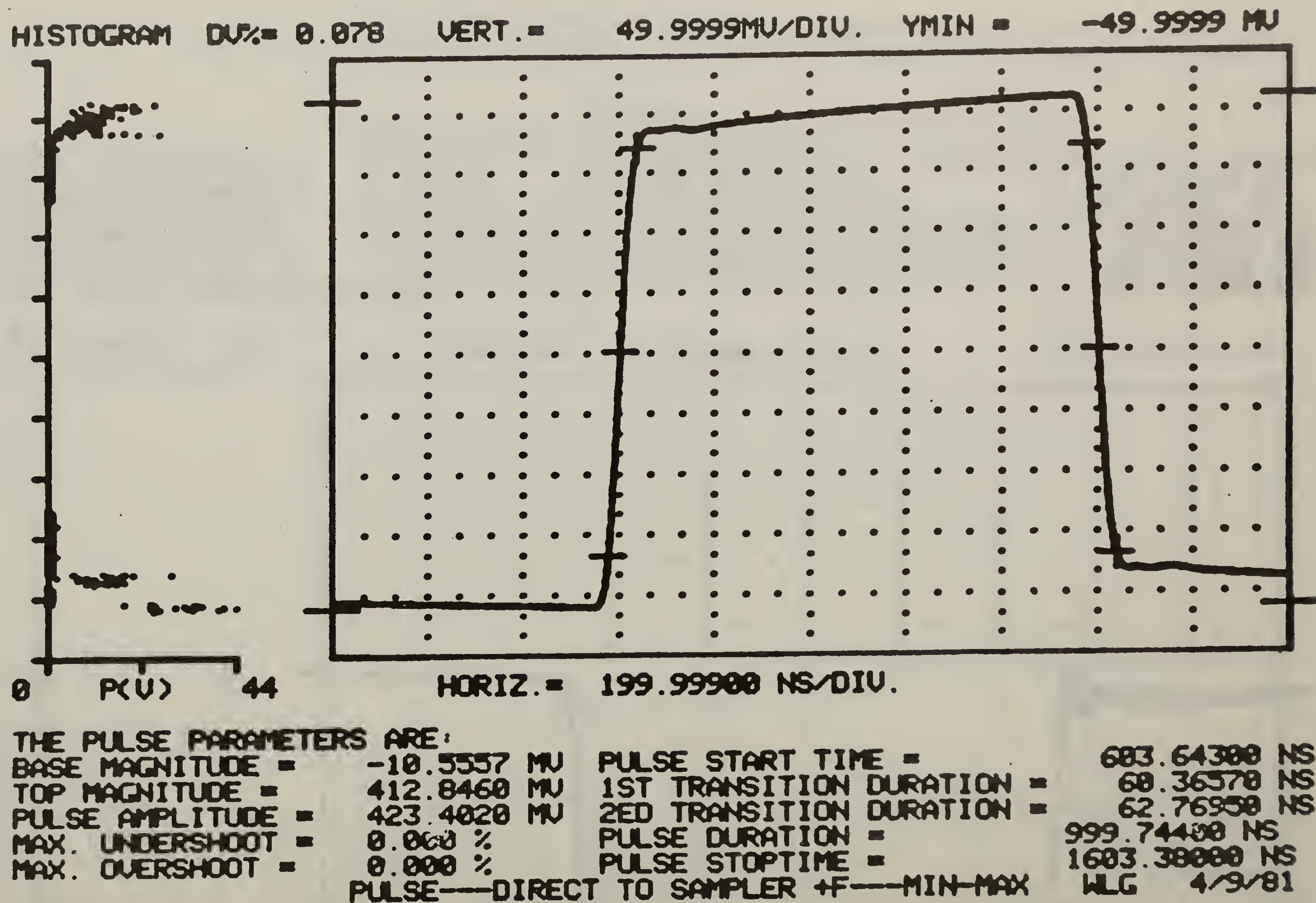


Figure 34a. NBS pulse source 1000 ns pulse direct to APMS sampler with 50 ns NBS filter (MIN-MAX definition).

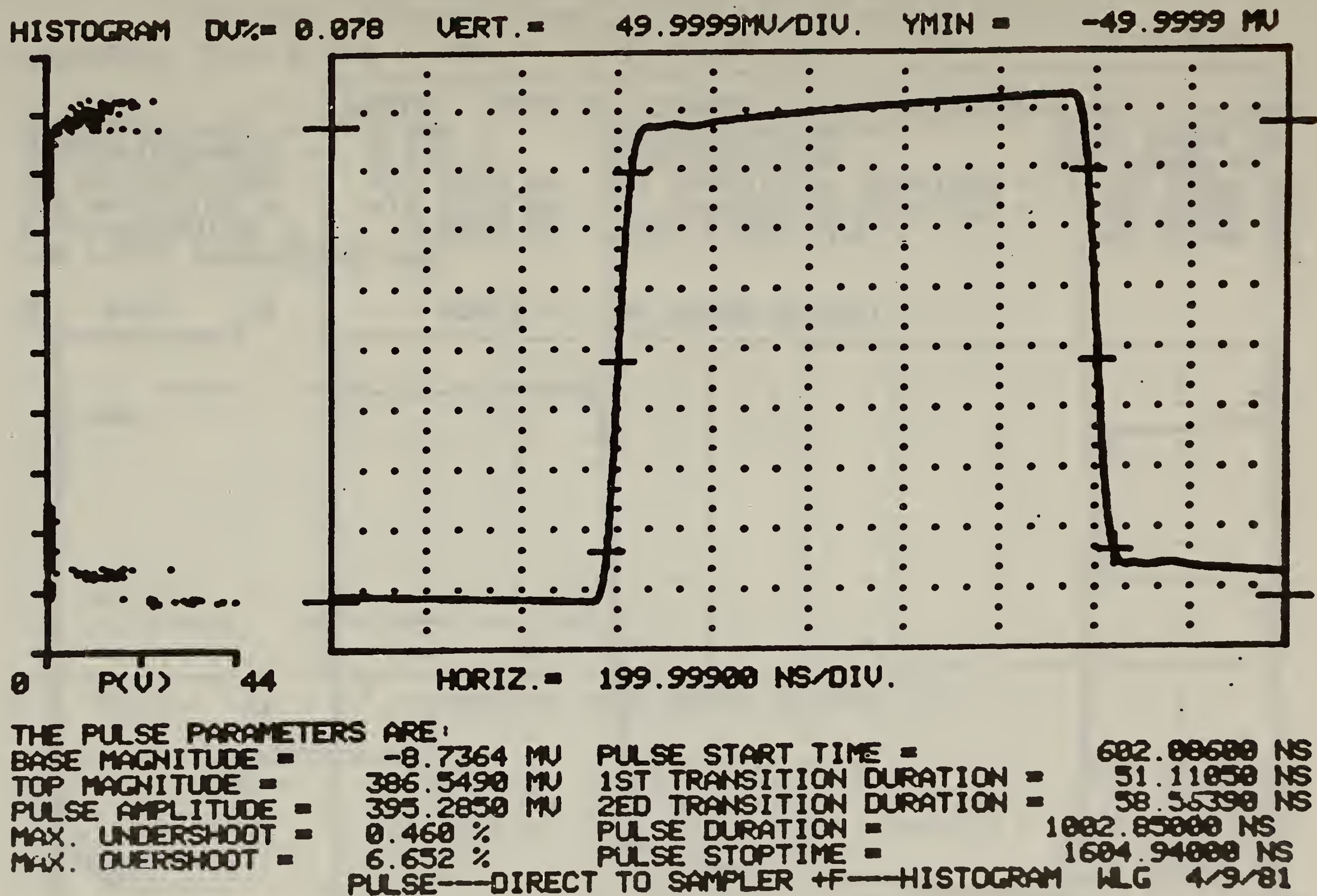
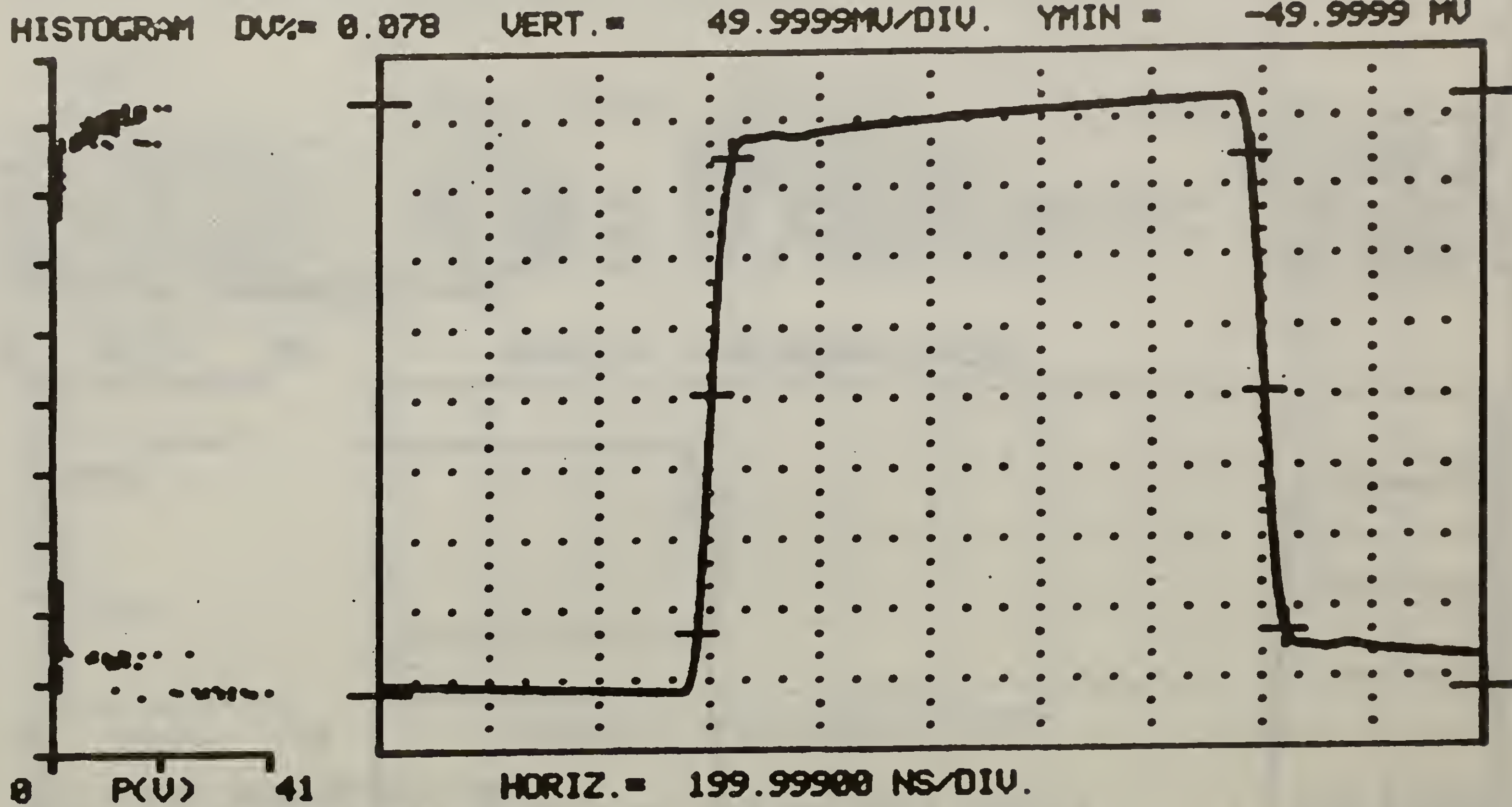


Figure 34b. NBS pulse source 1000 ns pulse direct to APMS sampler with 50 ns NBS filter (HISTOGRAM definition).

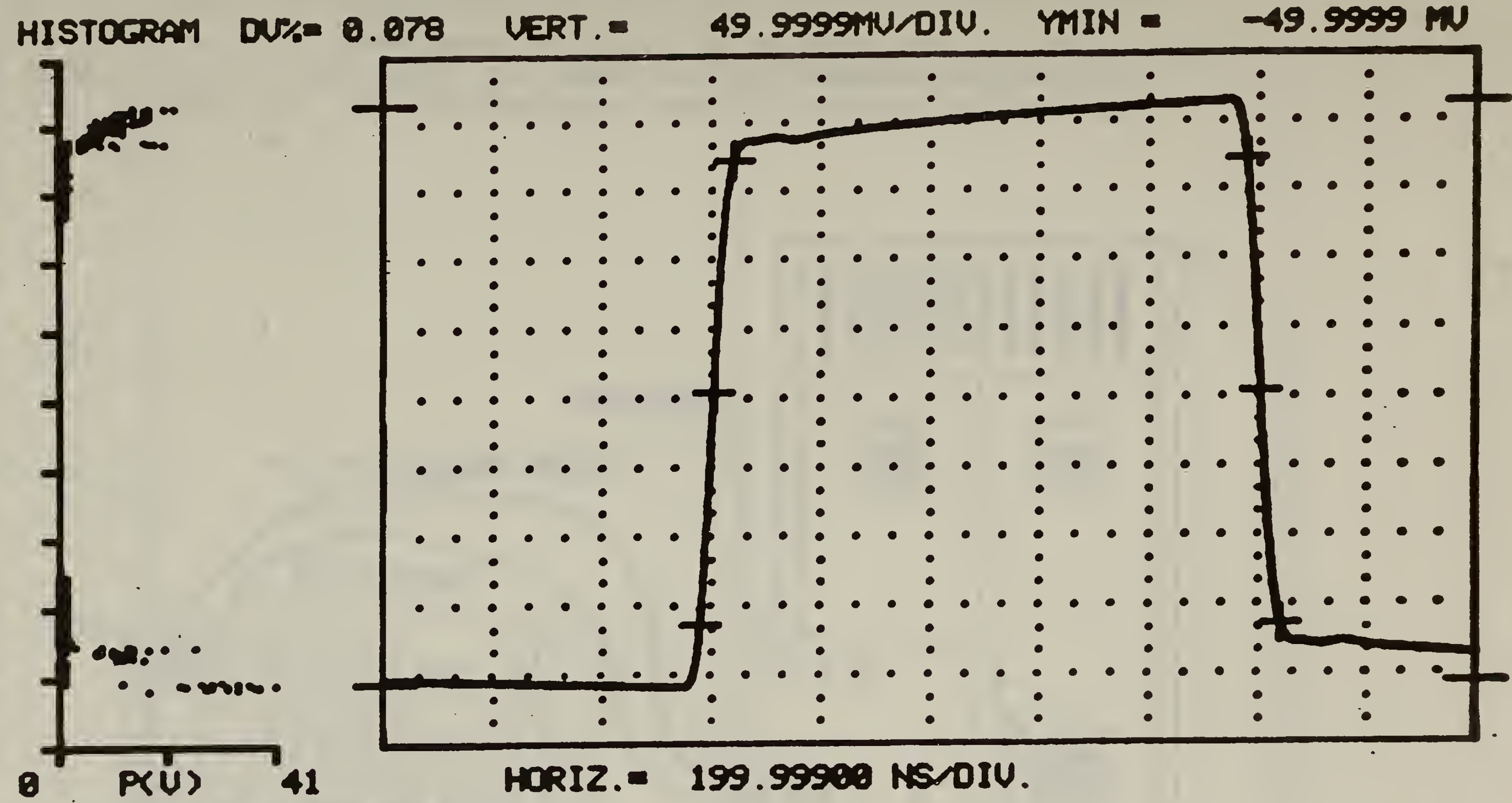


THE PULSE PARAMETERS ARE:

BASE MAGNITUDE =	-9.0865 MV	PULSE START TIME =	603.90900 NS
TOP MAGNITUDE =	414.8910 MV	1ST TRANSITION DURATION =	62.82050 NS
PULSE AMPLITUDE =	423.9780 MV	2ED TRANSITION DURATION =	65.37896 NS
MAX. UNDERSHOOT =	0.000 %	PULSE DURATION =	999.79500 NS
MAX. OVERSHOOT =	0.000 %	PULSE STOPTIME =	1603.70000 NS

PULSE---THRU ITT CONNECTOR +F---MIN-MAX WLG 4/9/81

Figure 35a. Same pulse as shown in figure 34a with addition of EQUATE PIU connector and NBS adapters (MIN-MAX definition).



THE PULSE PARAMETERS ARE:
BASE MAGNITUDE = -6.2710 MV
TOP MAGNITUDE = 414.0620 MV
PULSE AMPLITUDE = 420.3330 MV
MAX. UNDERSHOOT = 0.669 %
MAX. OVERSHOOT = 0.197 %
PULSE START TIME = 604.04000 NS
1ST TRANSITION DURATION = 61.89770 NS
2ED TRANSITION DURATION = 63.41720 NS
PULSE DURATION = 999.52900 NS
PULSE STOPTIME = 1603.56000 NS
PULSE---THRU ITT CONNECTOR +F---HISTOGRAM WLG 4/9/81

Figure 35b. Same pulse as shown in figure 34b with addition of EQUATE PIU connector and NBS adapters (HISTOGRAM definition).

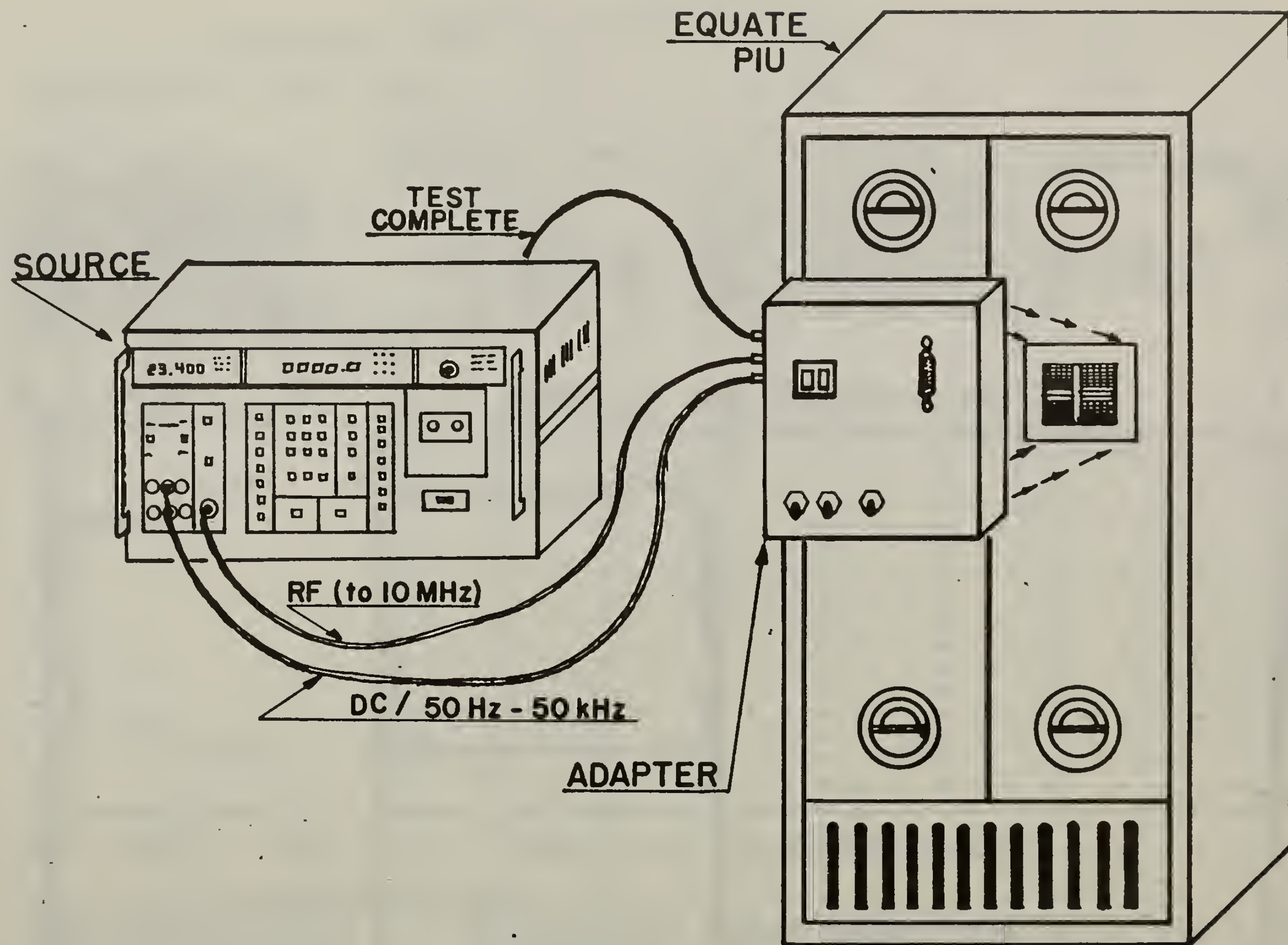


Figure 36. The interconnections between the source and the EQUATE station. All cables are 50 Ω impedance and have the same length as used in the calibration of the source and fixture.

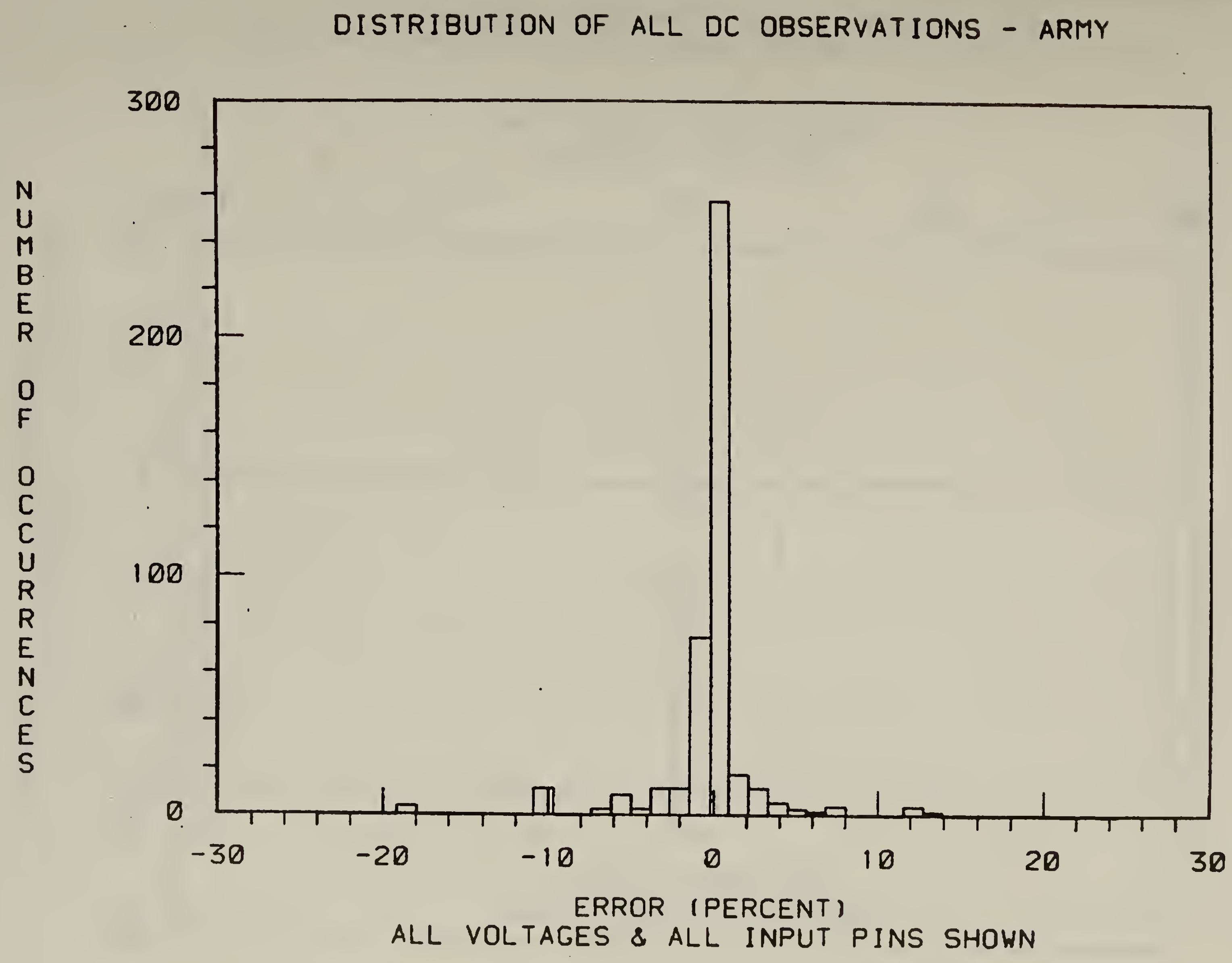


Figure 37. A histogram of the deviations from nominal (percent) for all dc voltage observations.

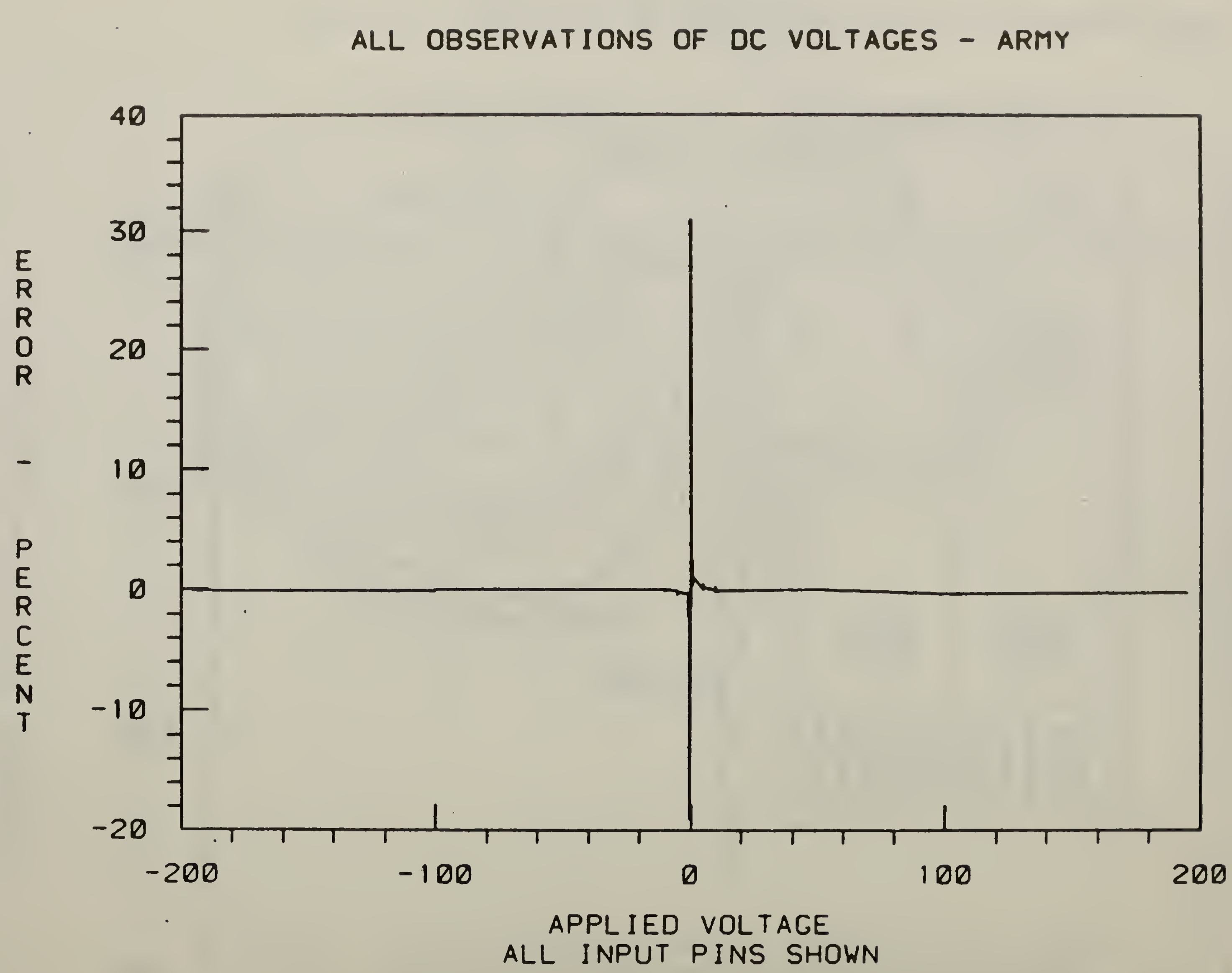


Figure 38. The error (percent) nominal plotted as a function of applied voltage over the range of -195 to +195 V dc.

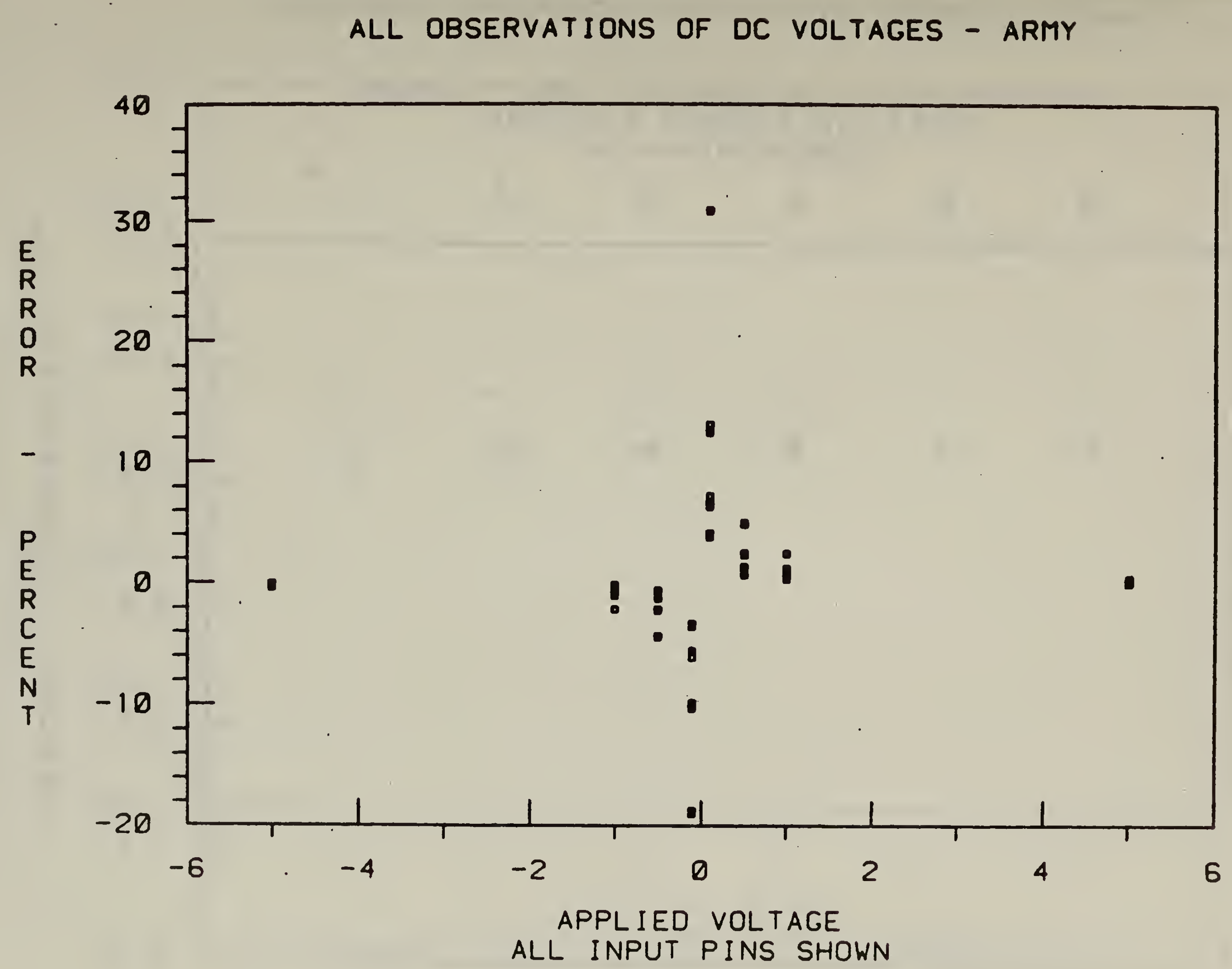


Figure 39. The error (percent) nominal plotted as a function of dc voltage over the range of -5 to +5 V dc.

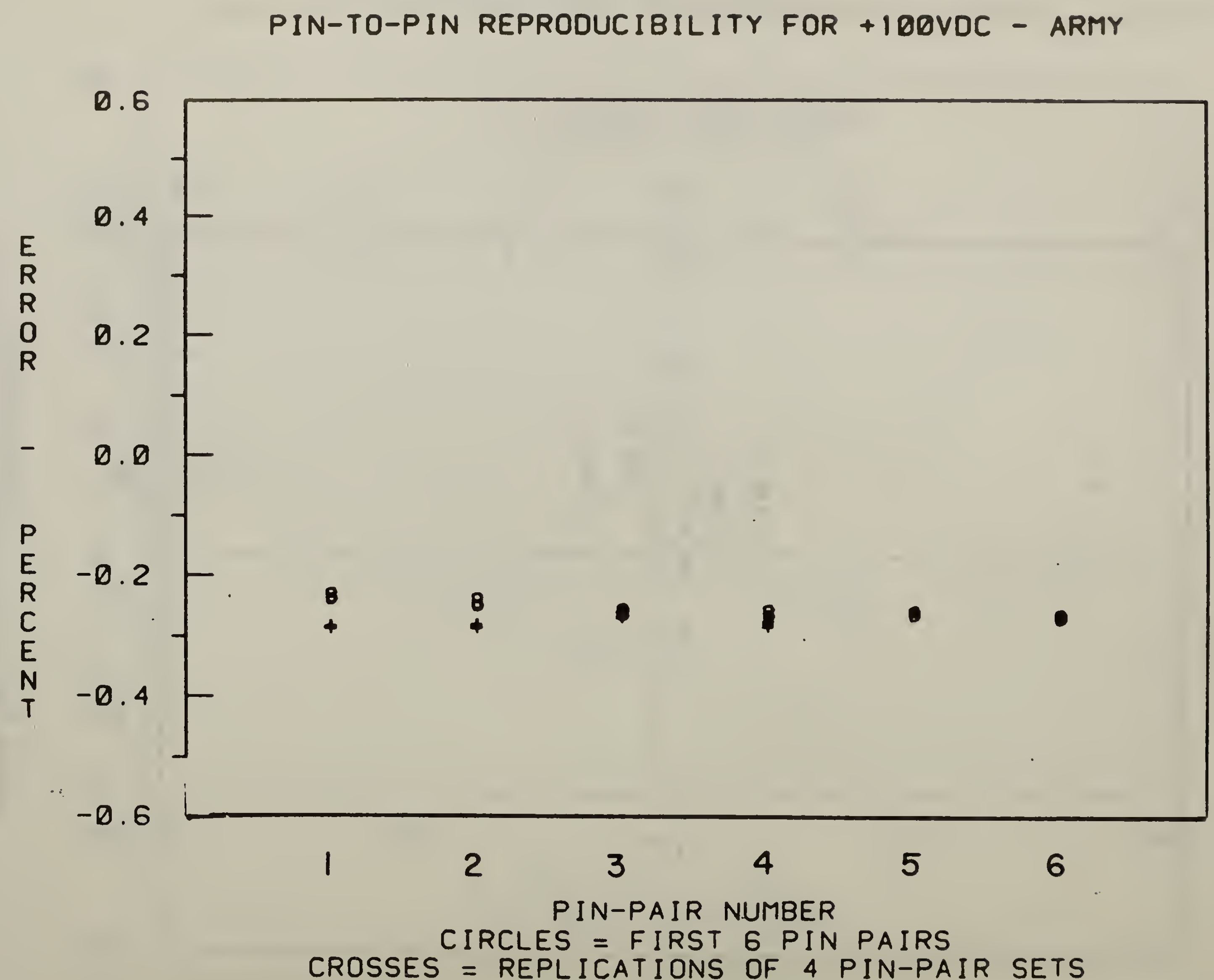


Figure 40a. The pin-to-pin reproducibility measured at +100 V dc.

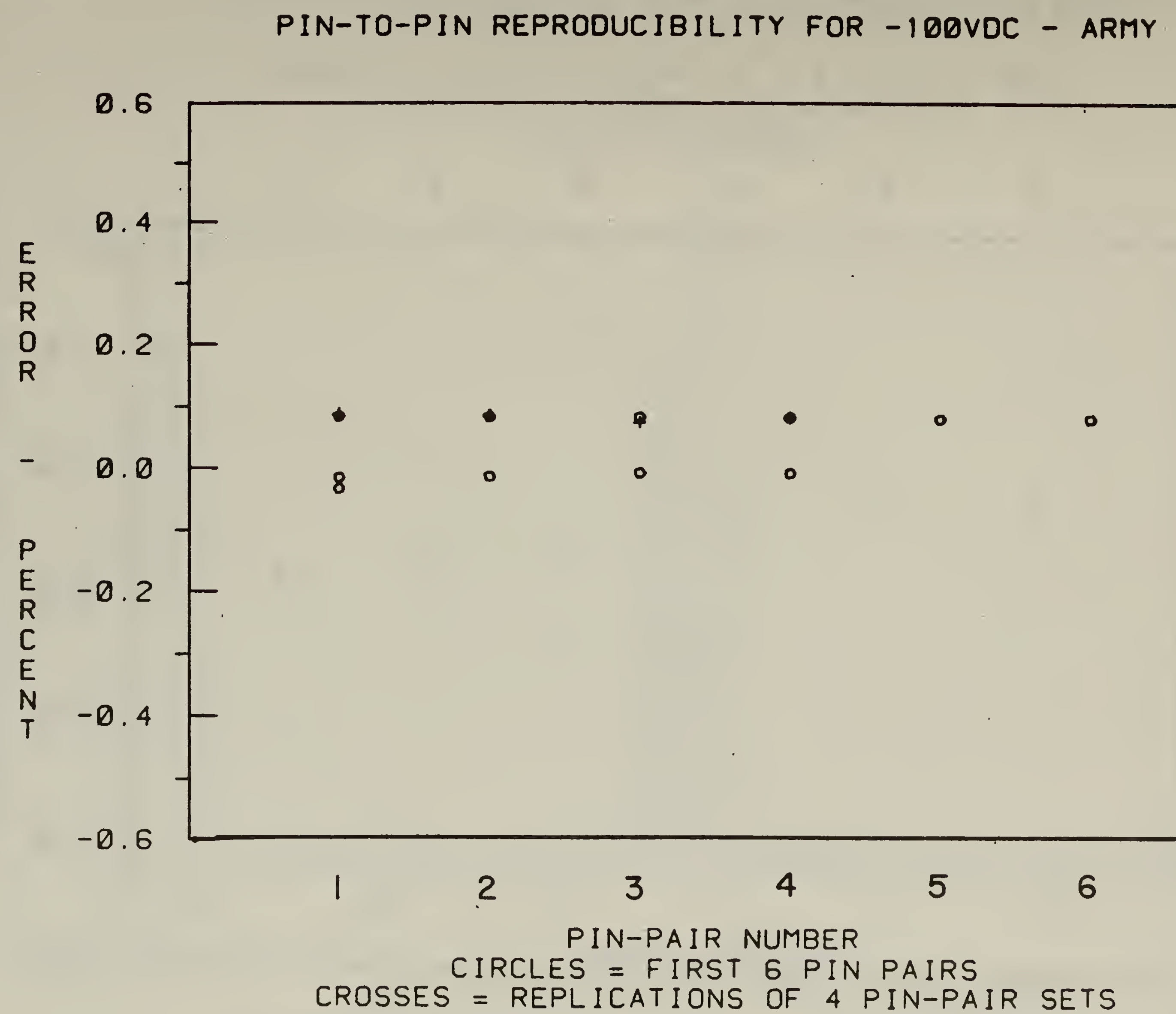


Figure 40b. The pin-to-pin reproducibility measured at -100 V dc.

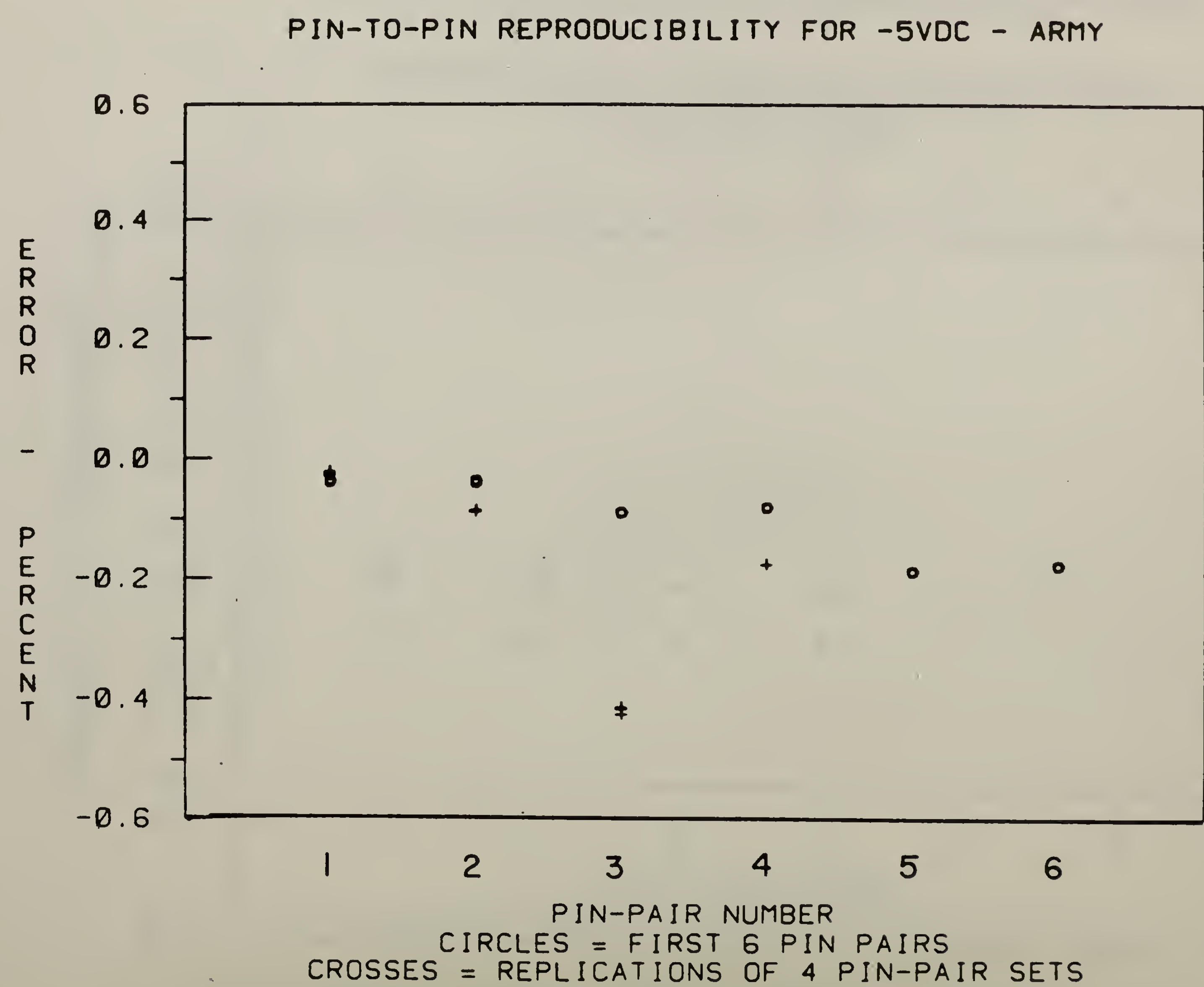


Figure 40c. The pin-to-pin reproducibility measured at -5 V dc.

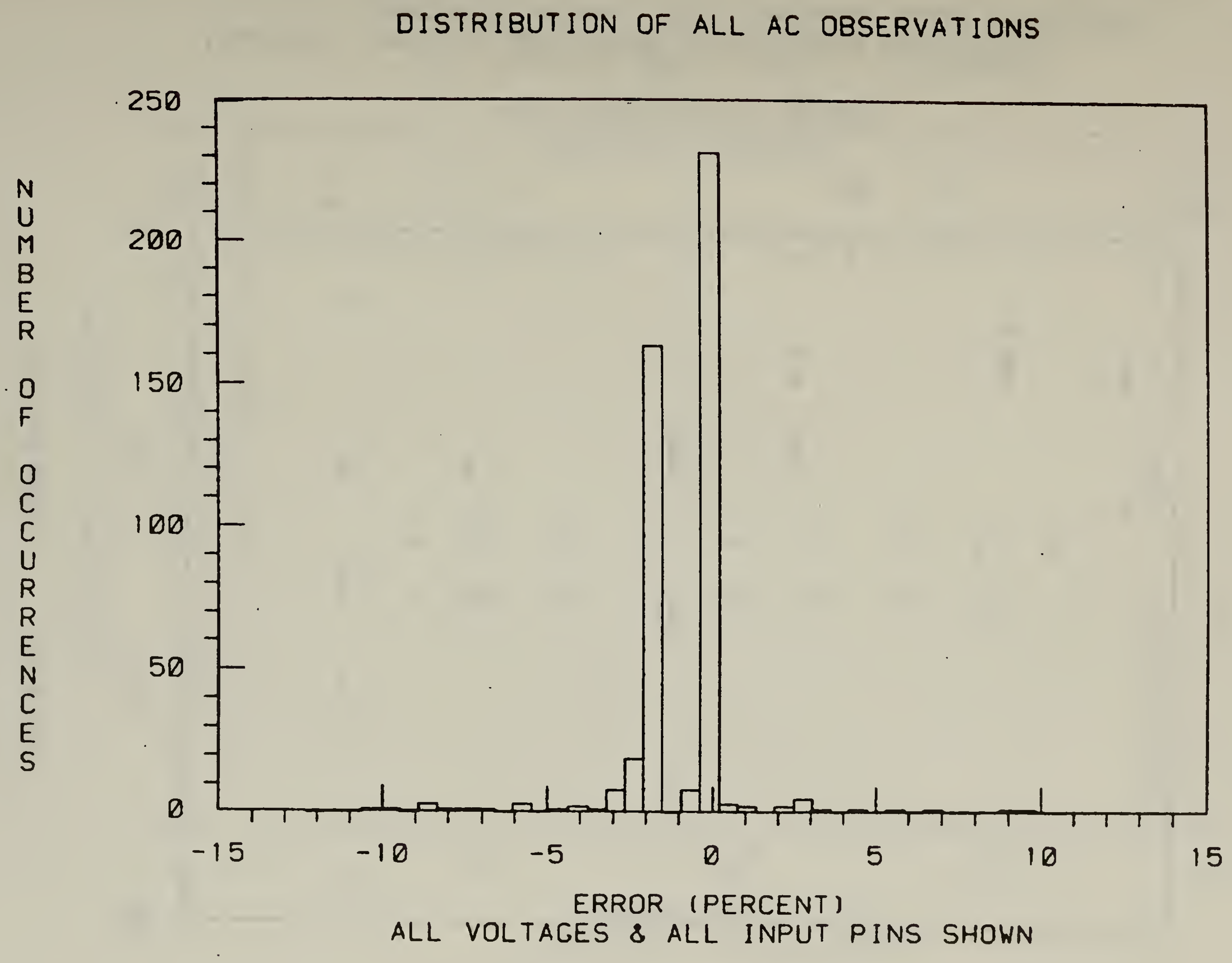


Figure 41. A histogram of the error (percent) for all ac voltage observations.

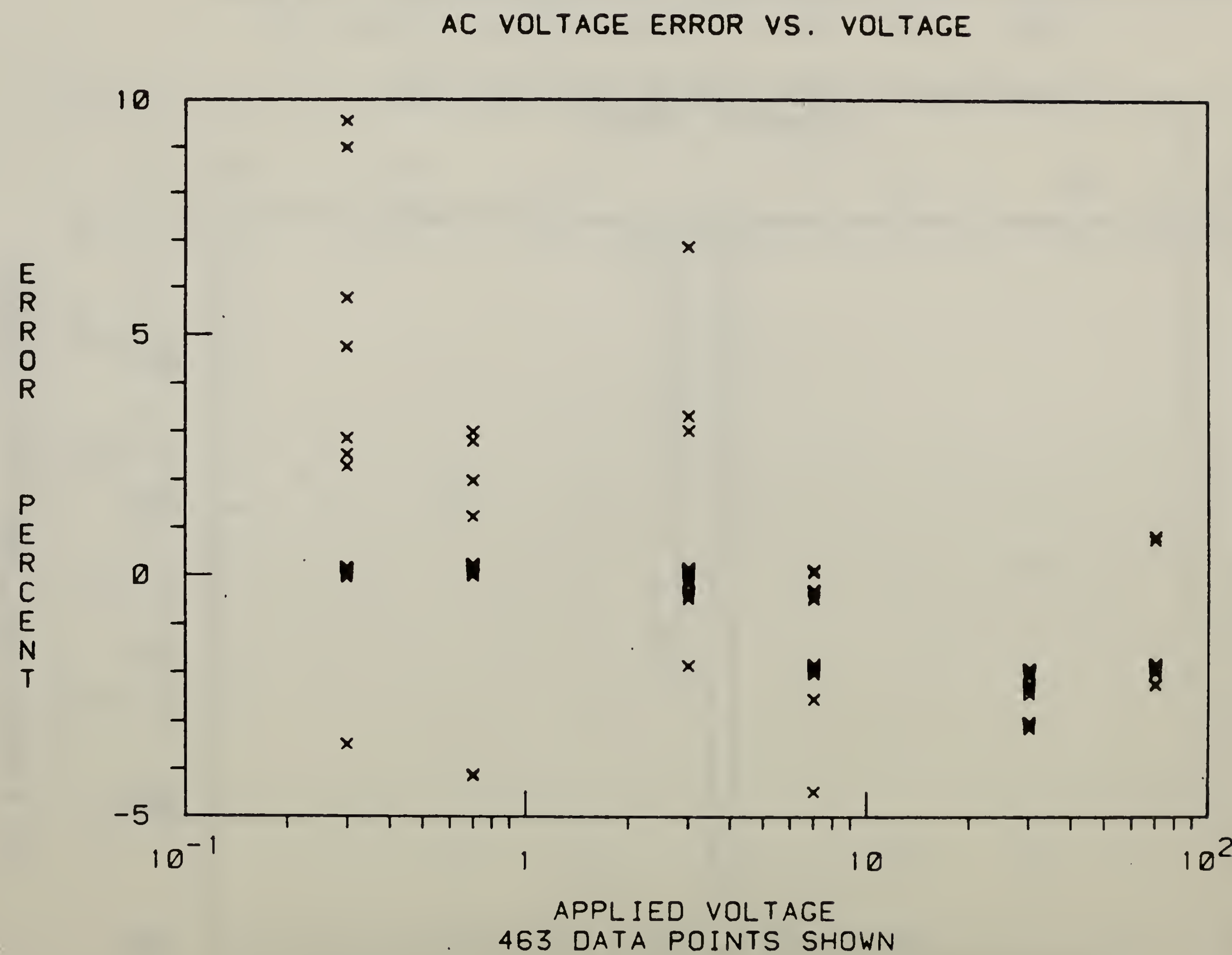


Figure 42. The error (percent) for the ac voltage observations as a function of voltage. Notice the abrupt change in the points at 7 V ac.

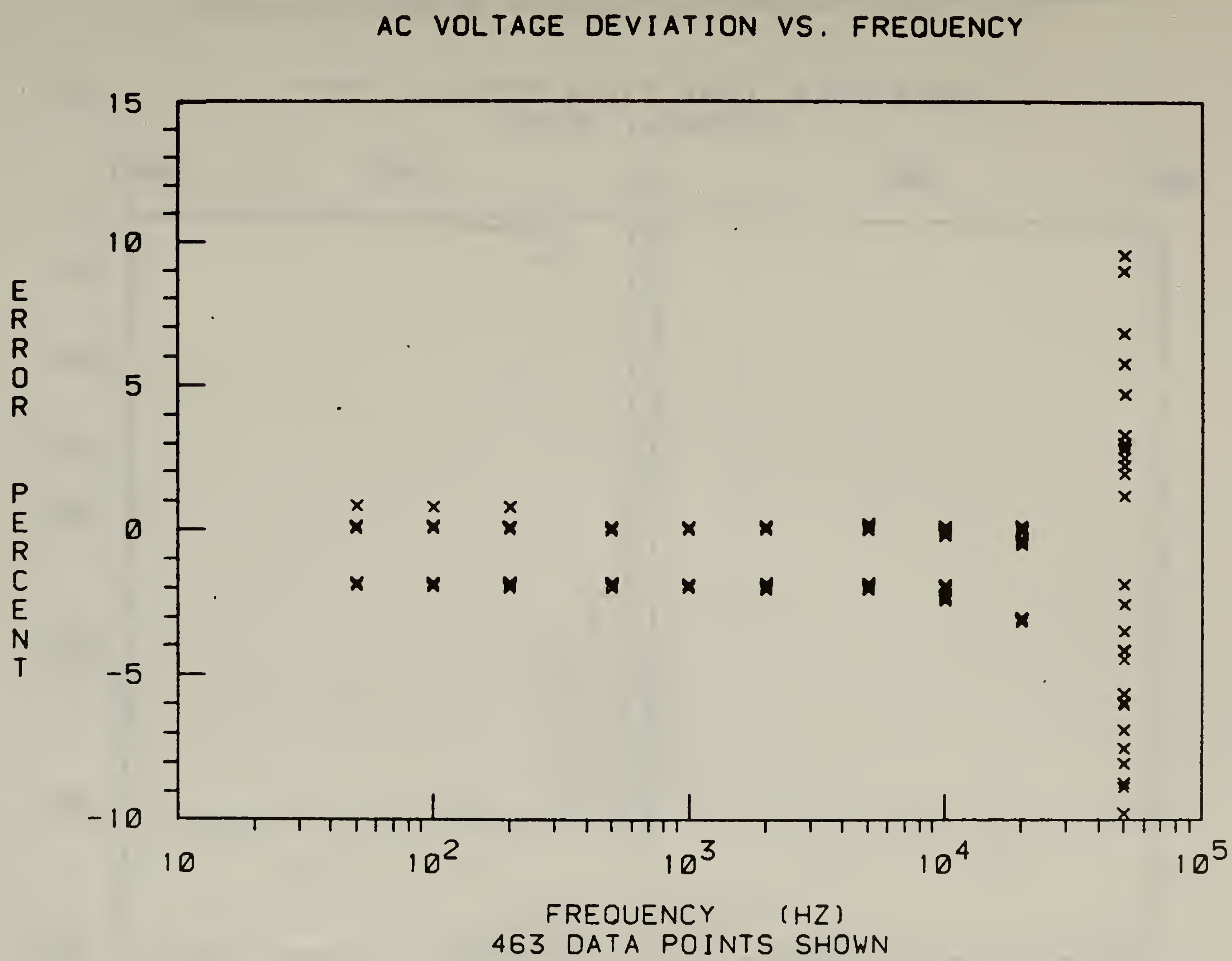


Figure 43. The error (percent) for the ac voltage observations as a function of frequency. Notice the dispersion of points at 50 kHz.

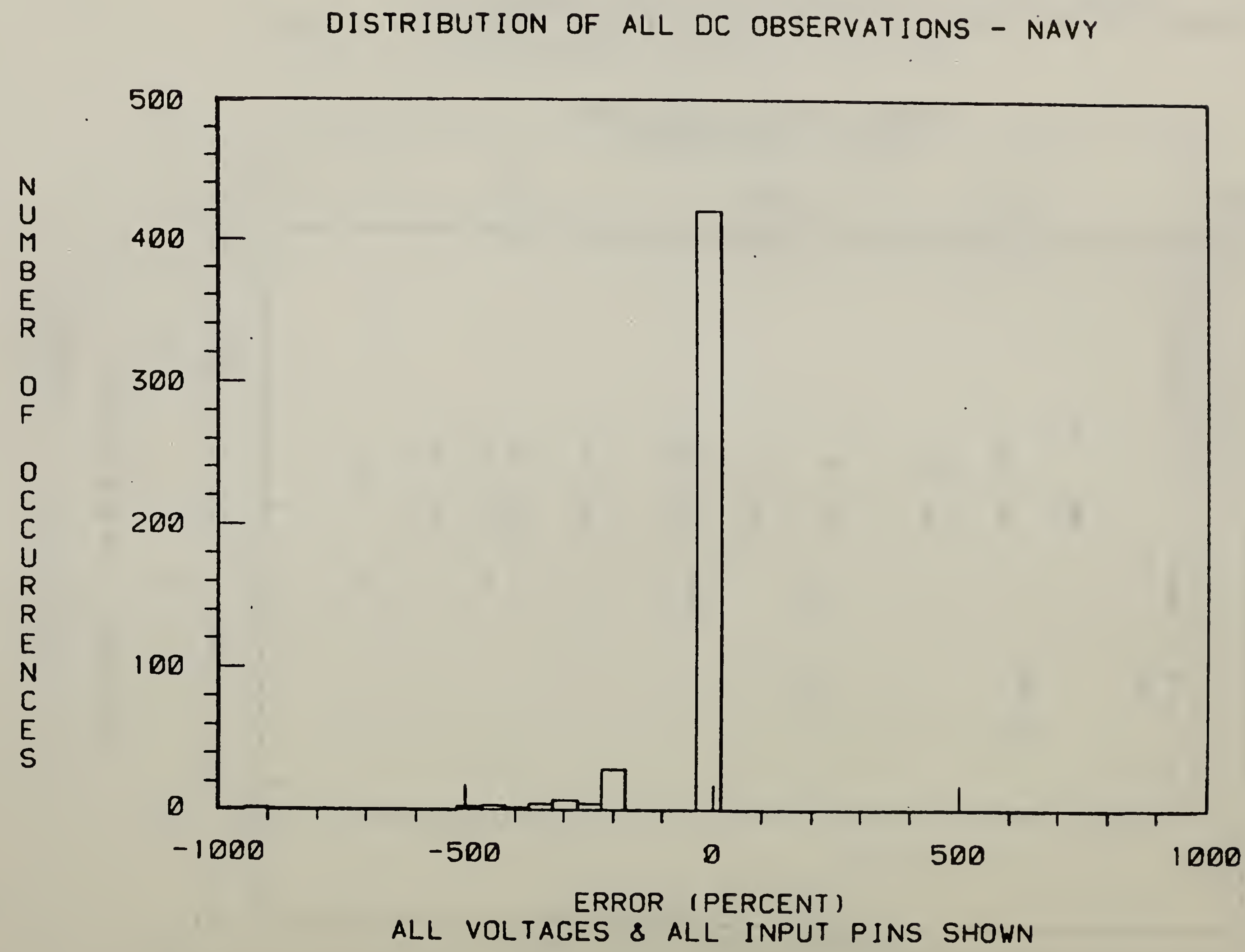


Figure 44. A histogram of the error (percent) for all the dc voltage observations.

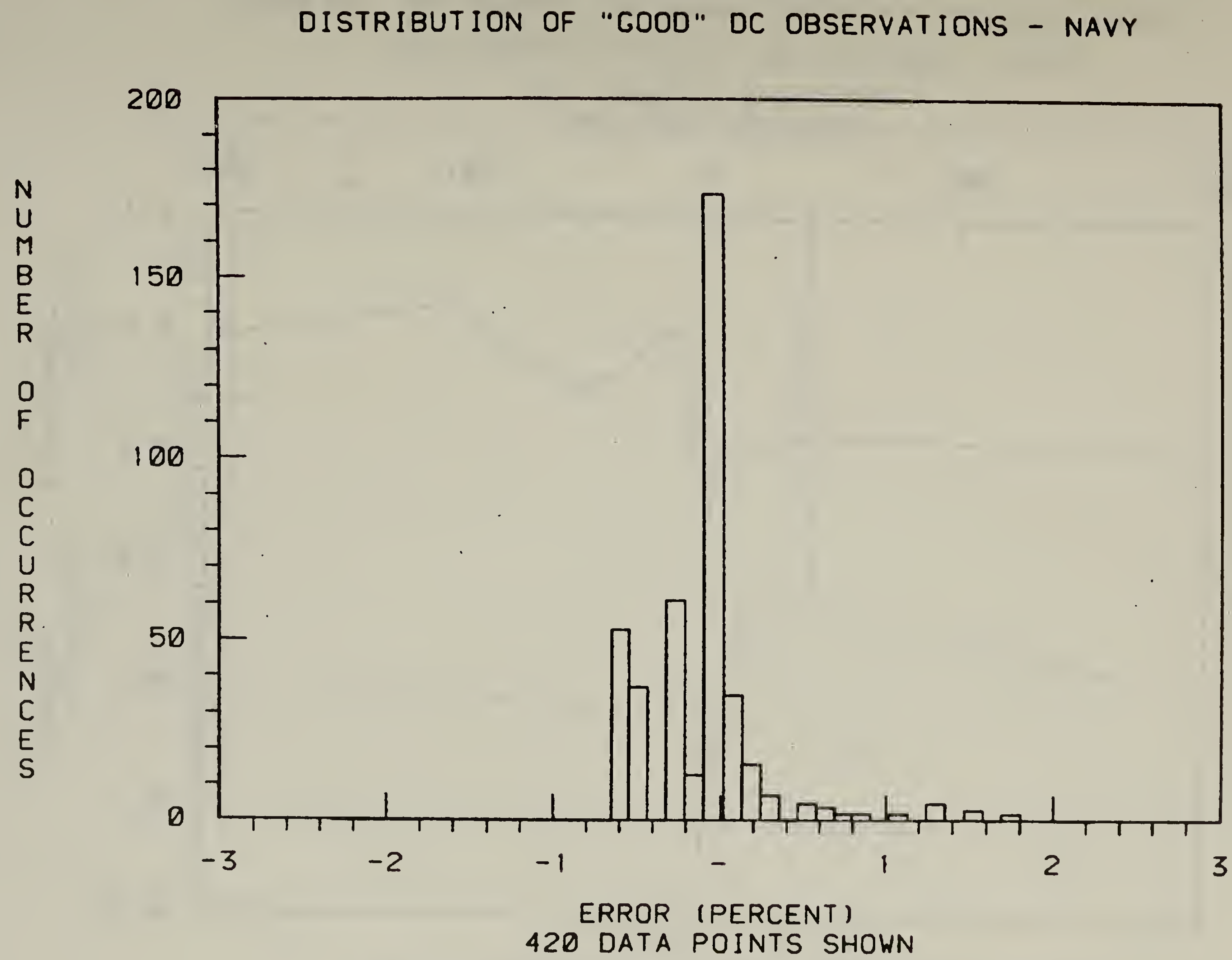


Figure 45. A histogram of all dc observations with those points removed that were in error by more than 50 percent.

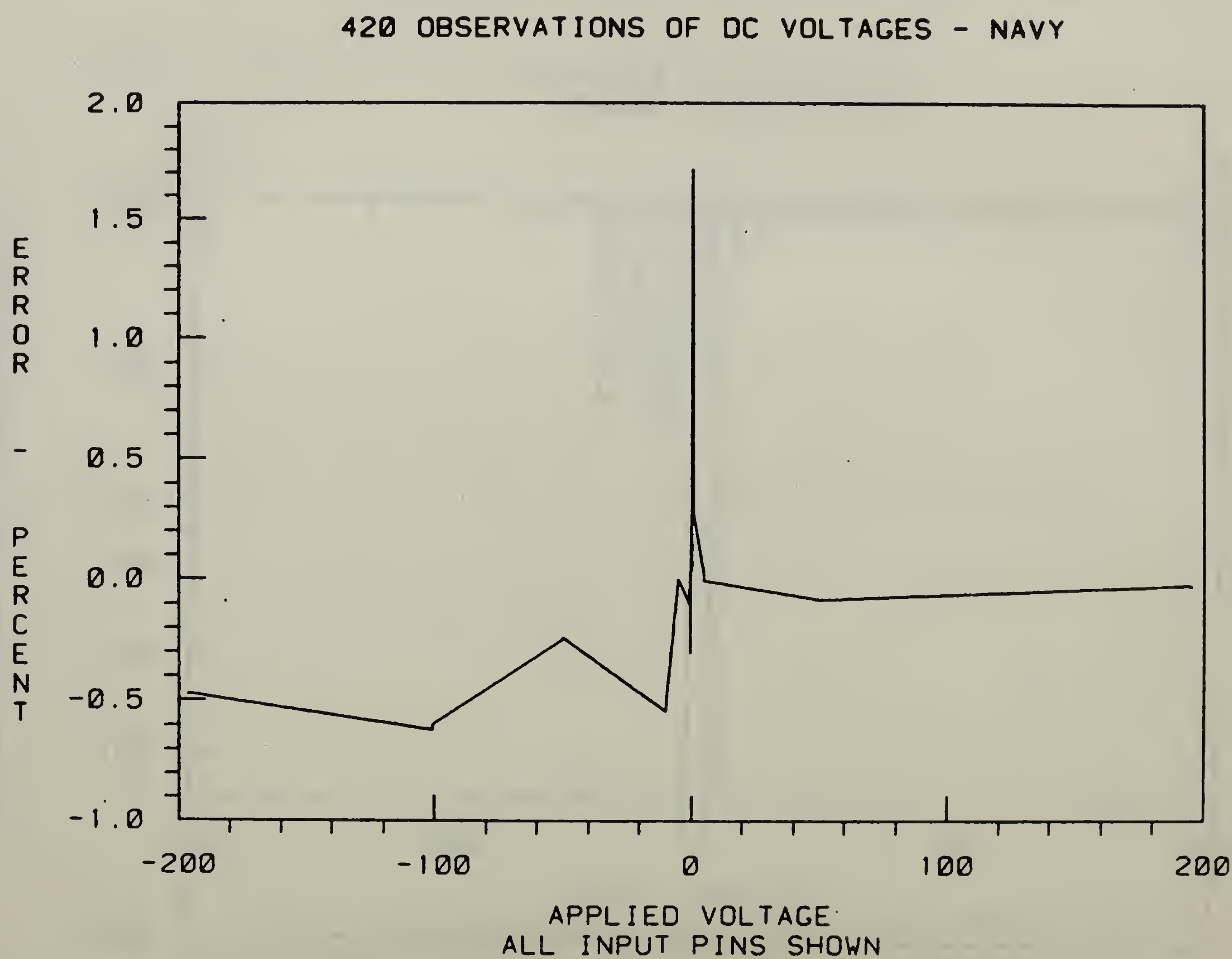


Figure 46. The deviation from nominal plotted as a function of voltage over the range of -195 V to +195 V dc.

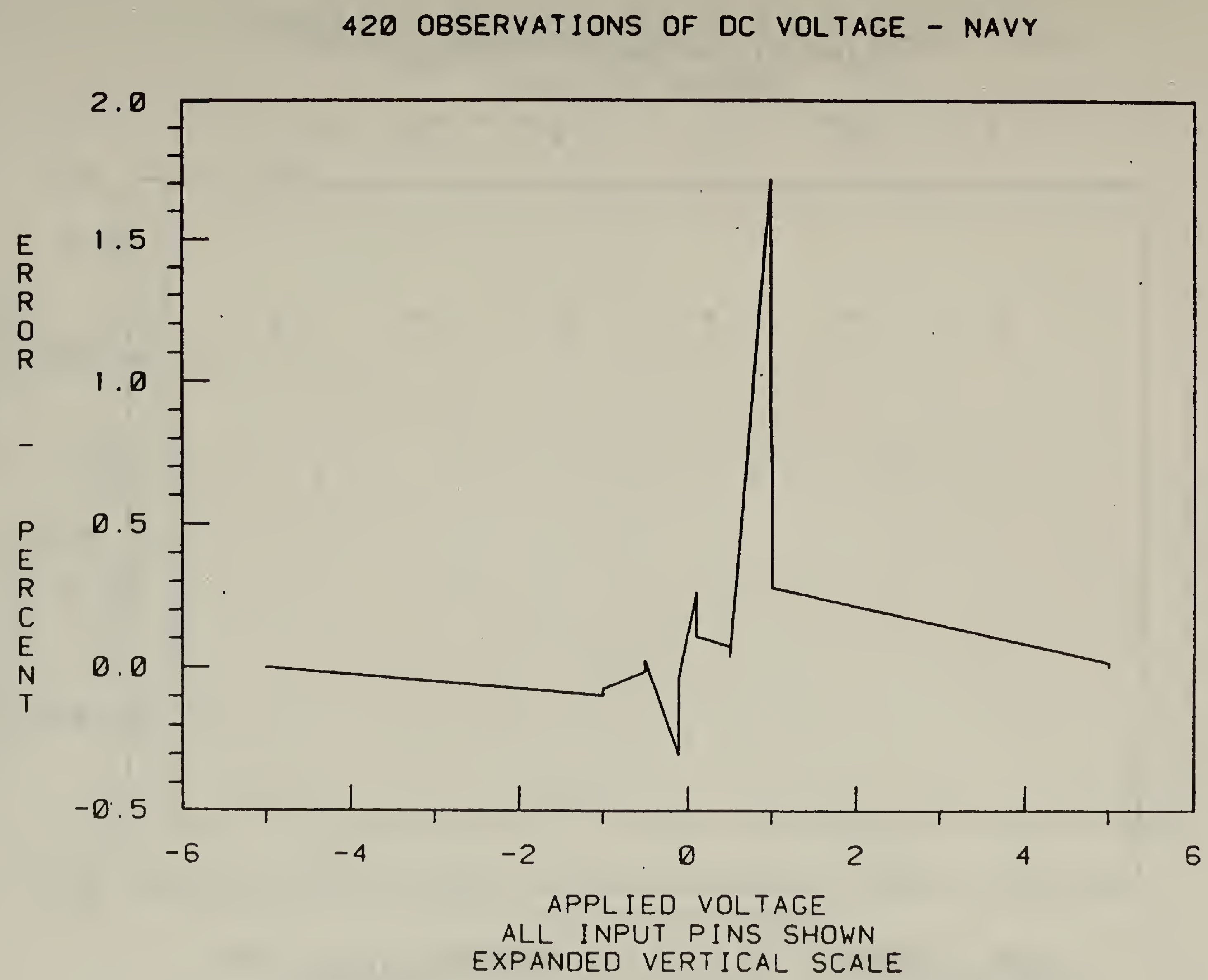


Figure 47. The deviation from nominal plotted as a function of voltage over the range of -5 V to +5 V dc.

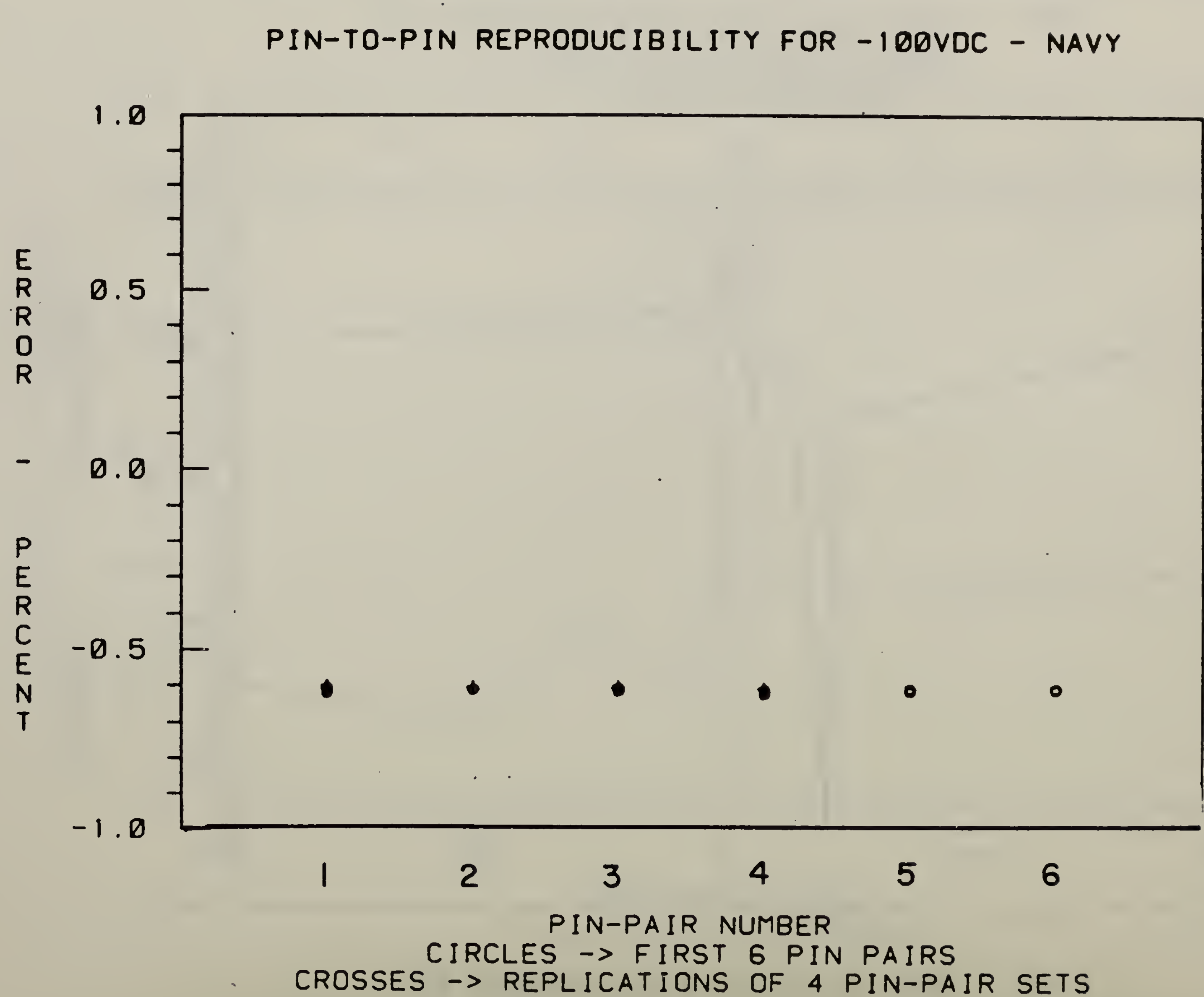


Figure 48. The pin-to-pin reproducibility measured at -100 V dc.

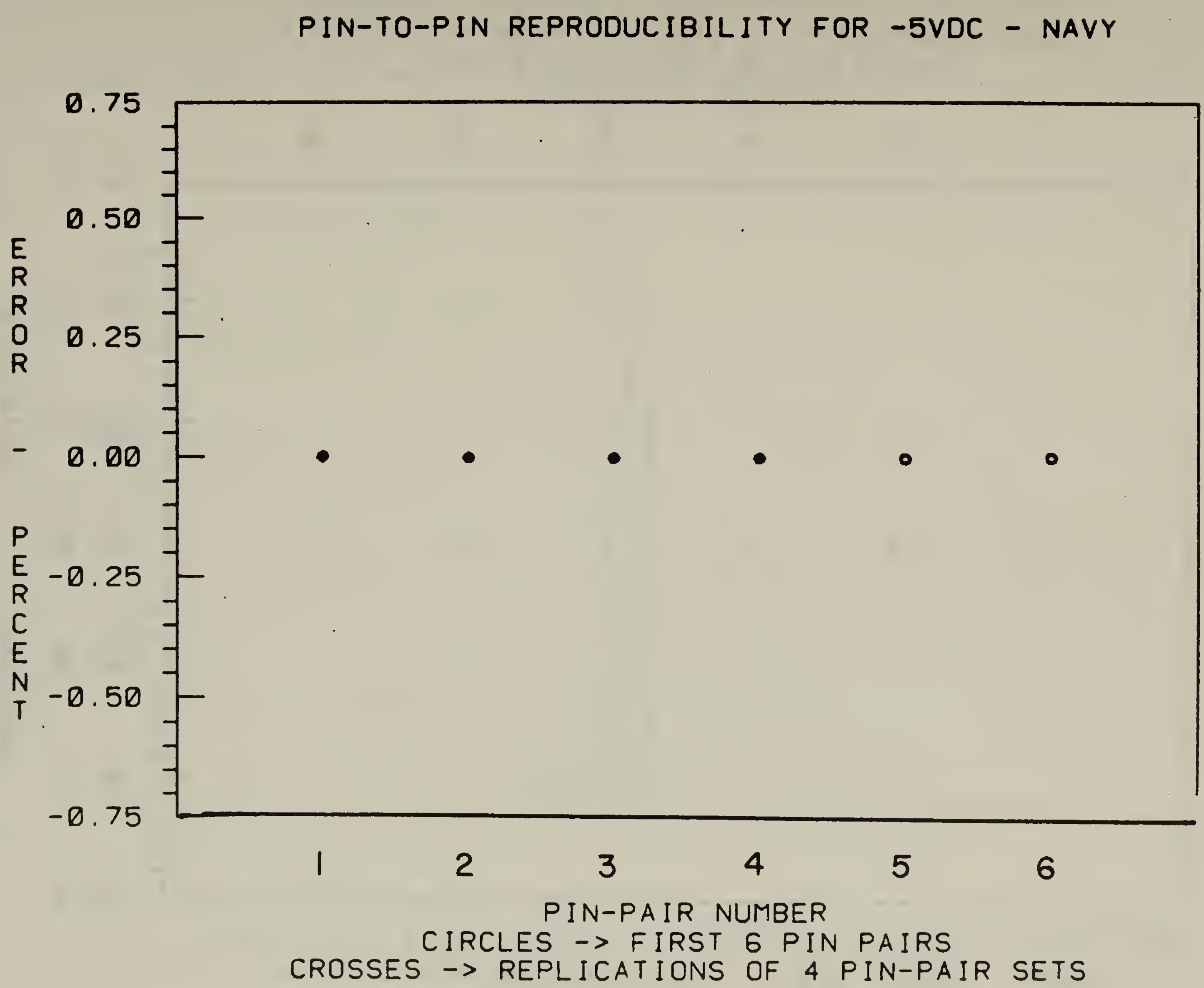


Figure 49. The pin-to-pin reproducibility measured at -5 V dc.

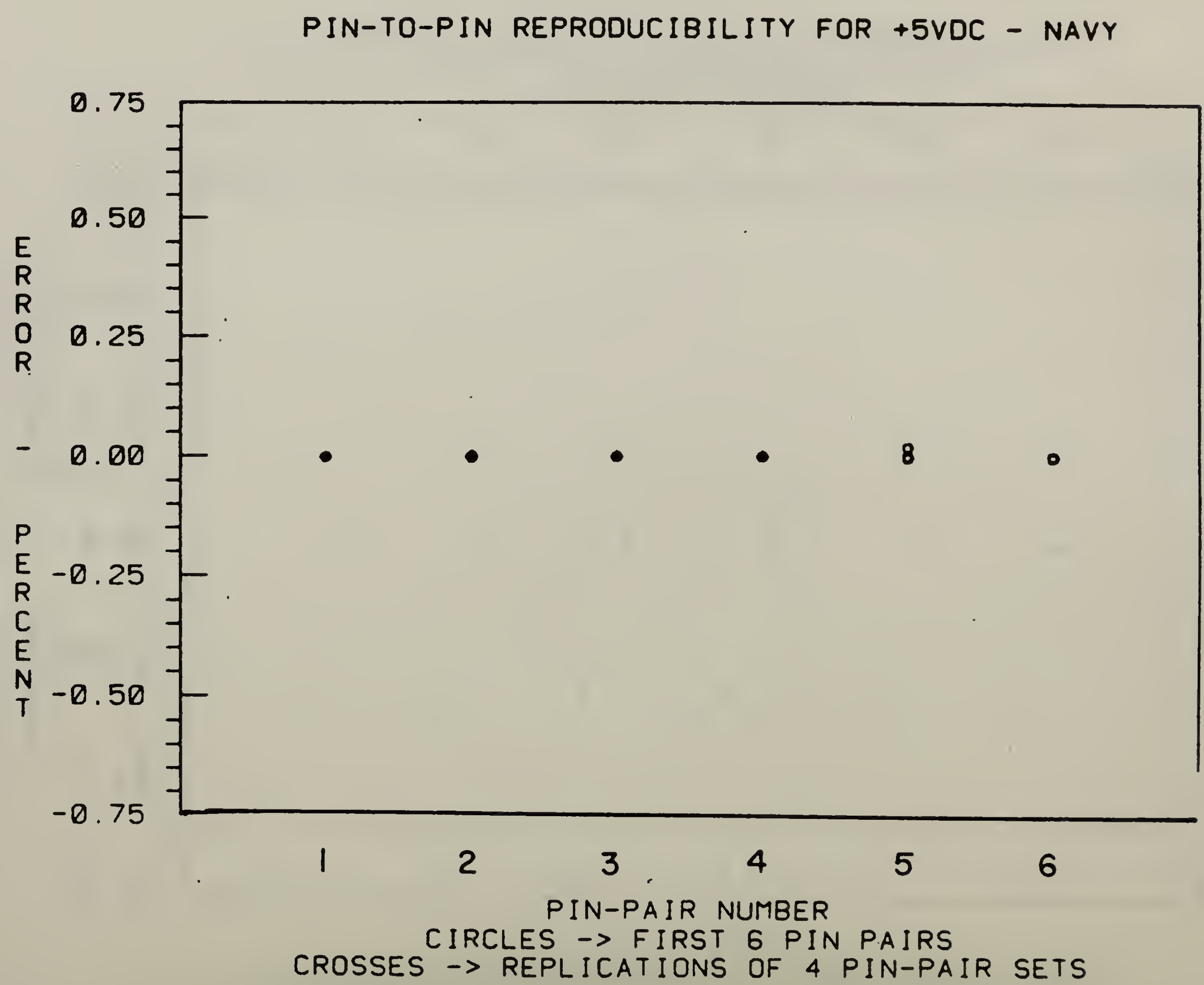


Figure 50. The pin-to-pin reproducibility measured at +5 V dc.

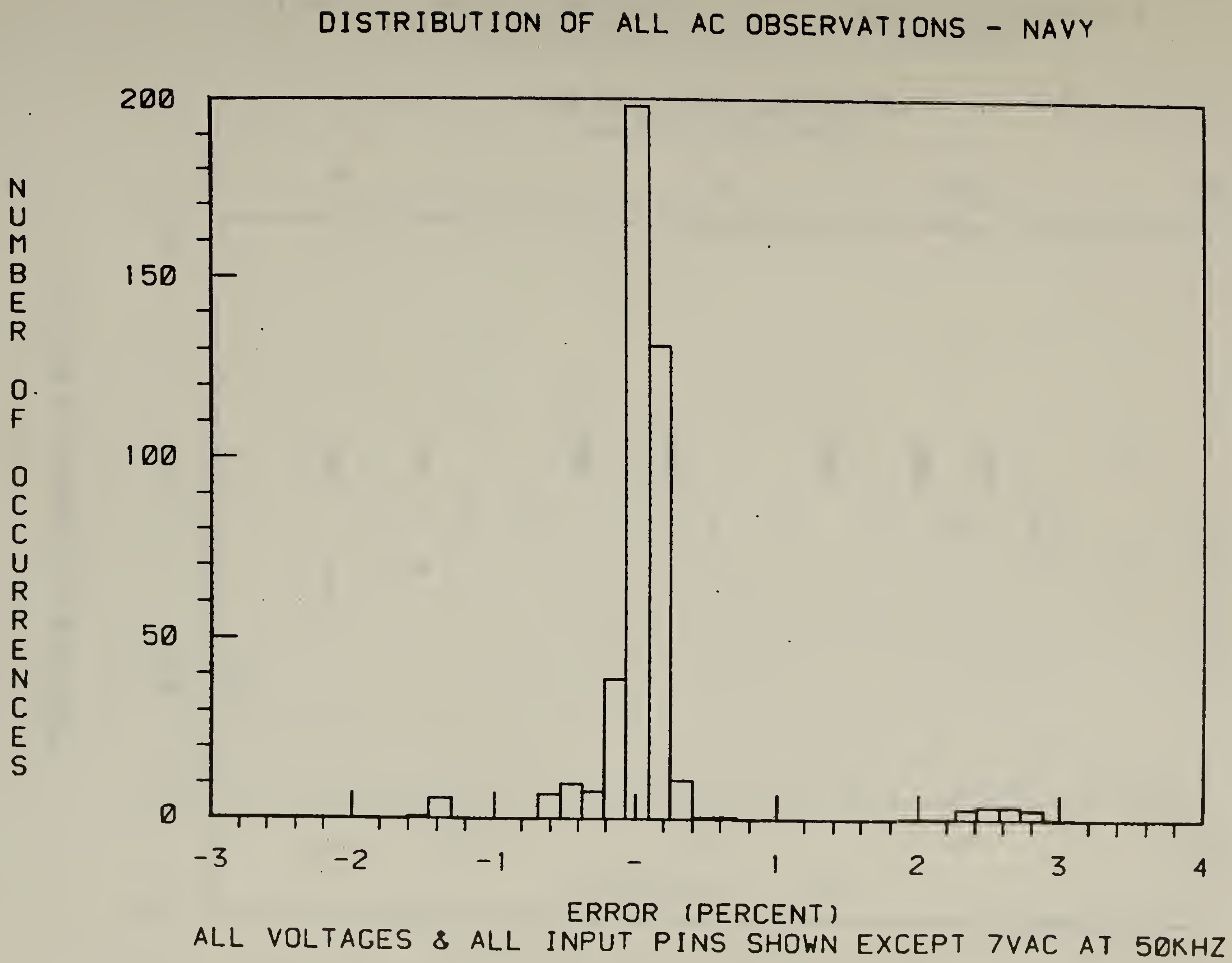


Figure 51. A histogram of the deviations of ac voltages as measured by the EQUATE station with those points removed that were in error by more than 50 percent.

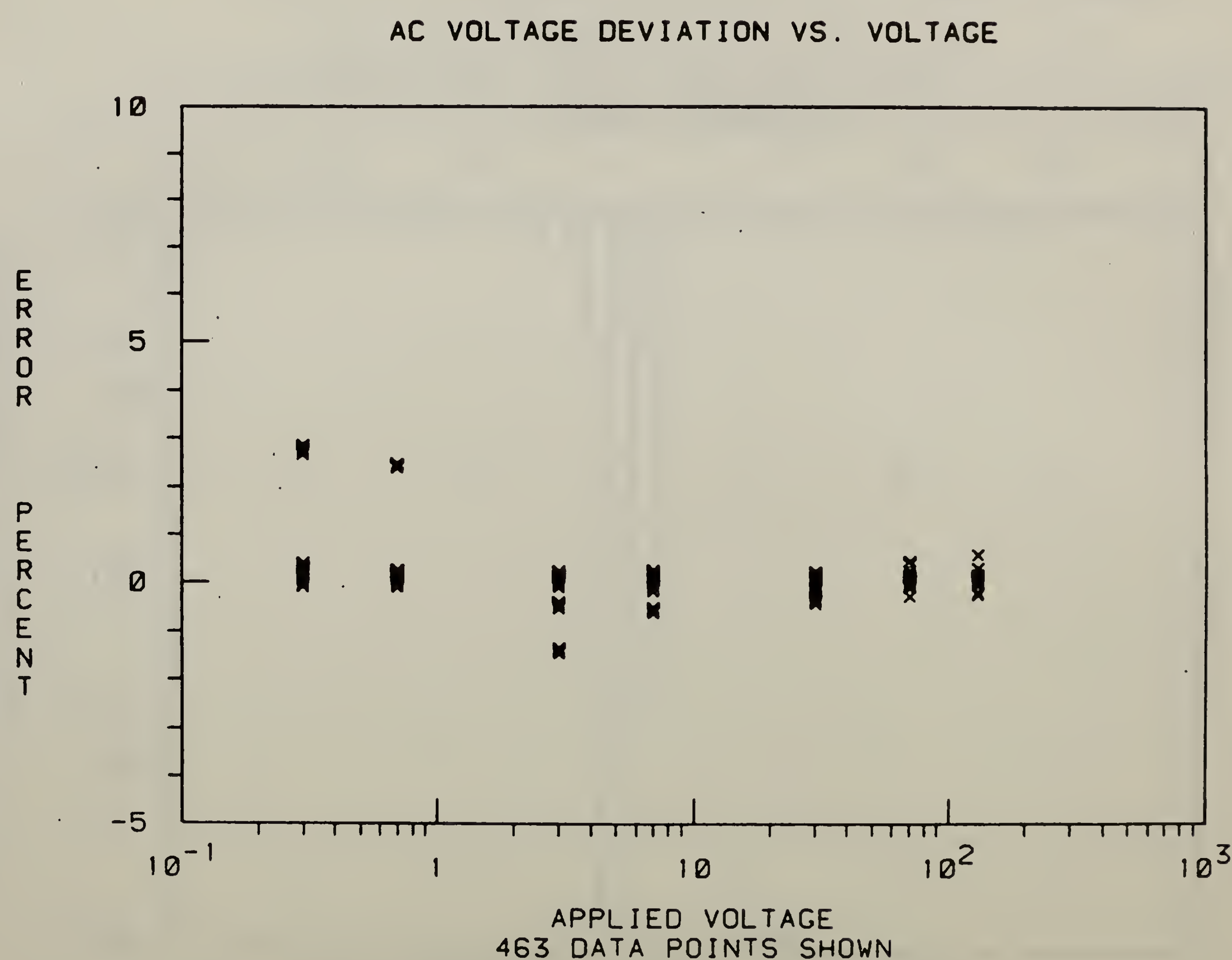


Figure 52. The error (percent) for the ac voltage observations as a function of voltage.

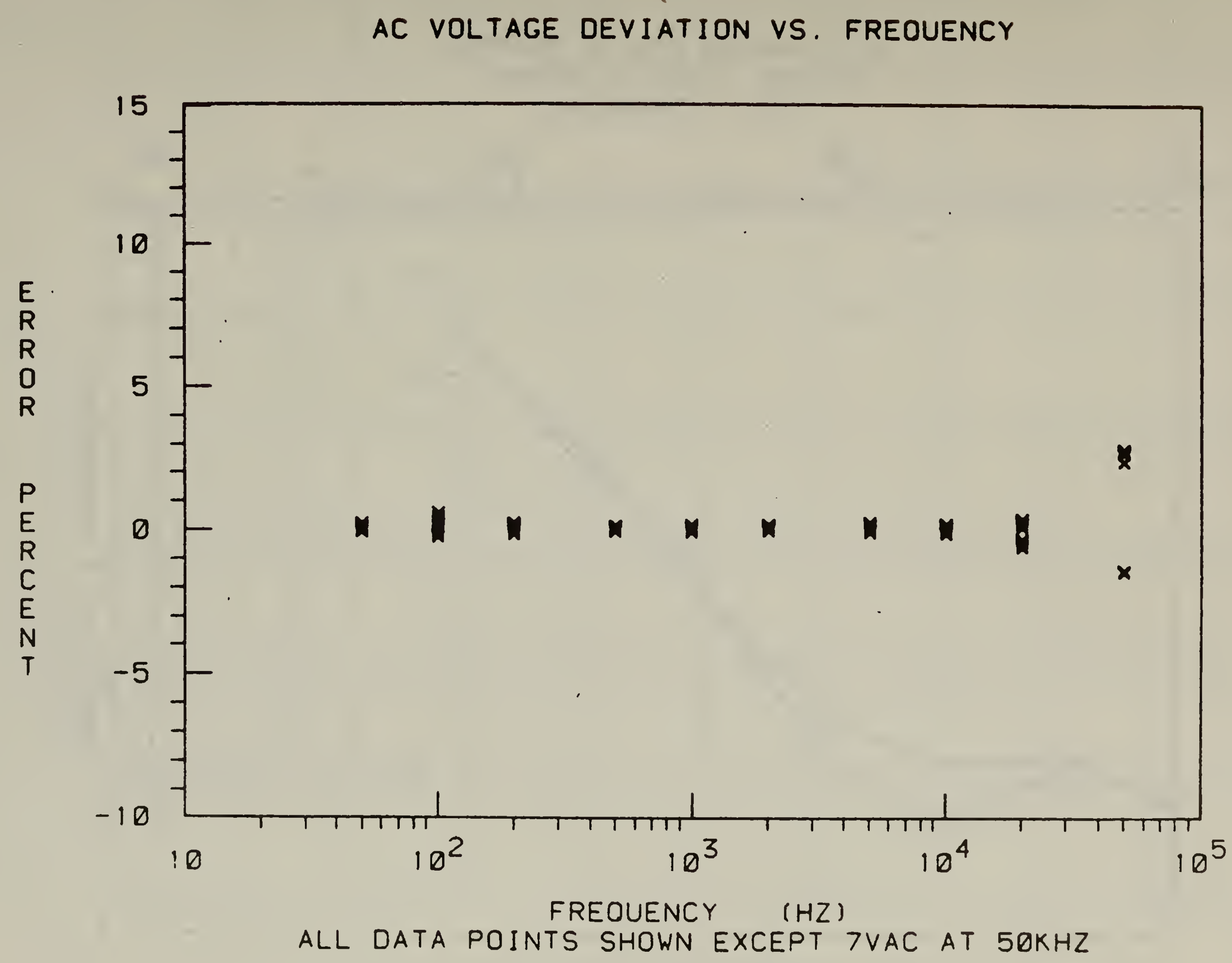


Figure 53. The error (percent) for the ac voltage observations as a function of frequency. Notice the dispersion of points at 50 kHz is to a lesser extent but similar in form to that shown in figure 43.

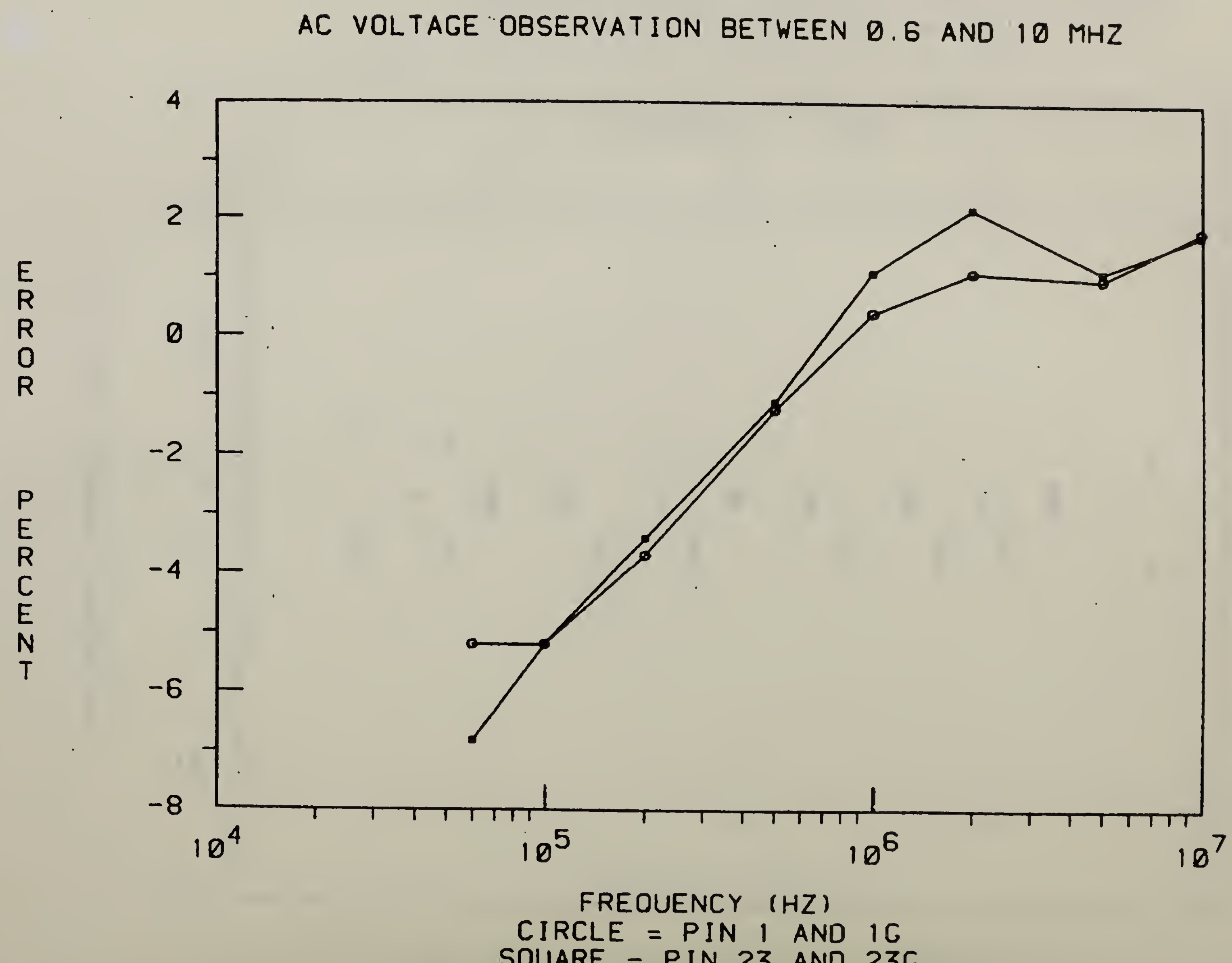


Figure 54. The error (percent) of ac voltage observations between 0.6 and 10 MHz.

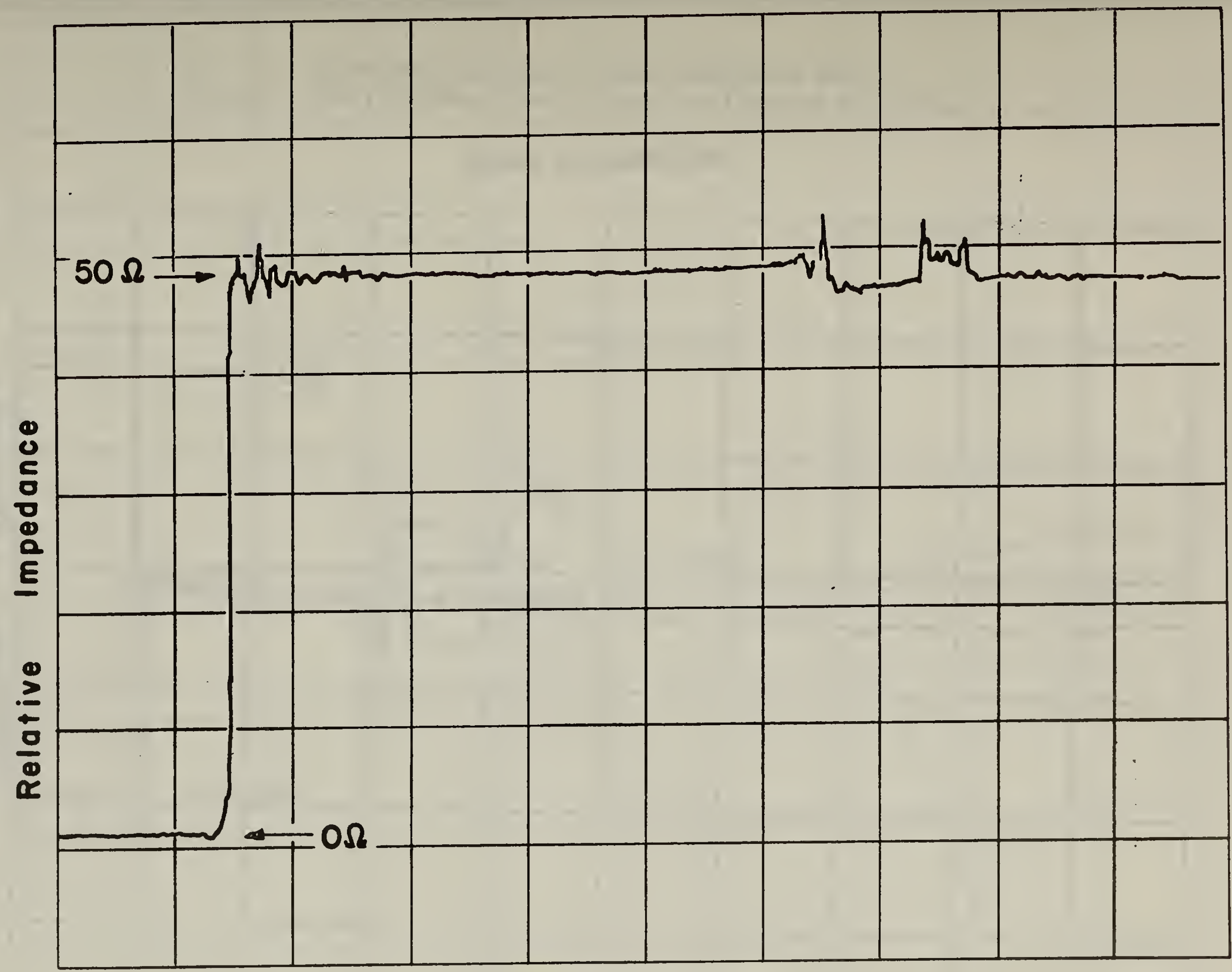


Figure 55. A time domain reflectometry signature of the 50 Ω DIU BNC connector port to EQUATE.

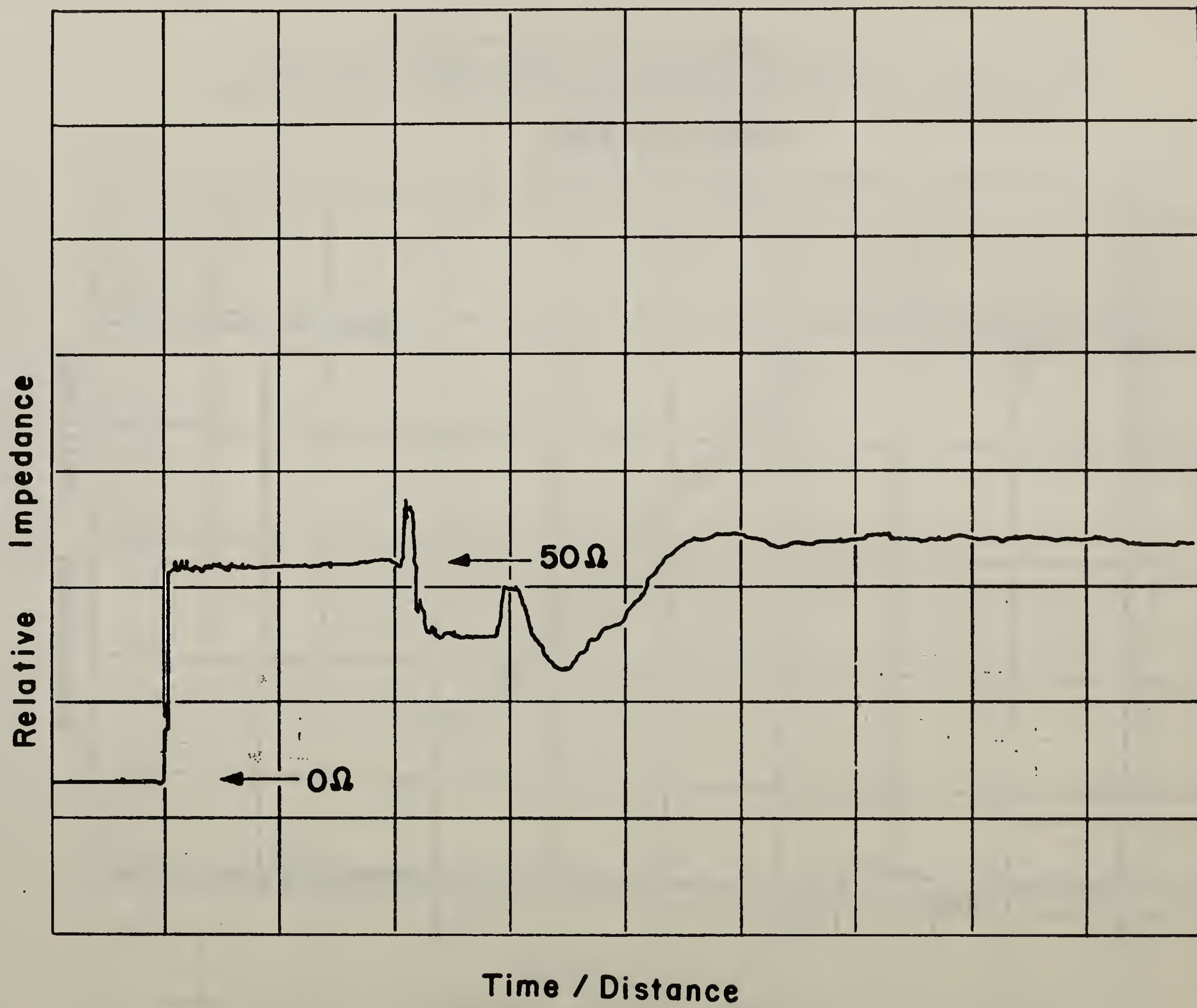


Figure 56. The time domain reflectometry signature of pin-pair 1 and 1S of the PIU input in the unbuffered mode.

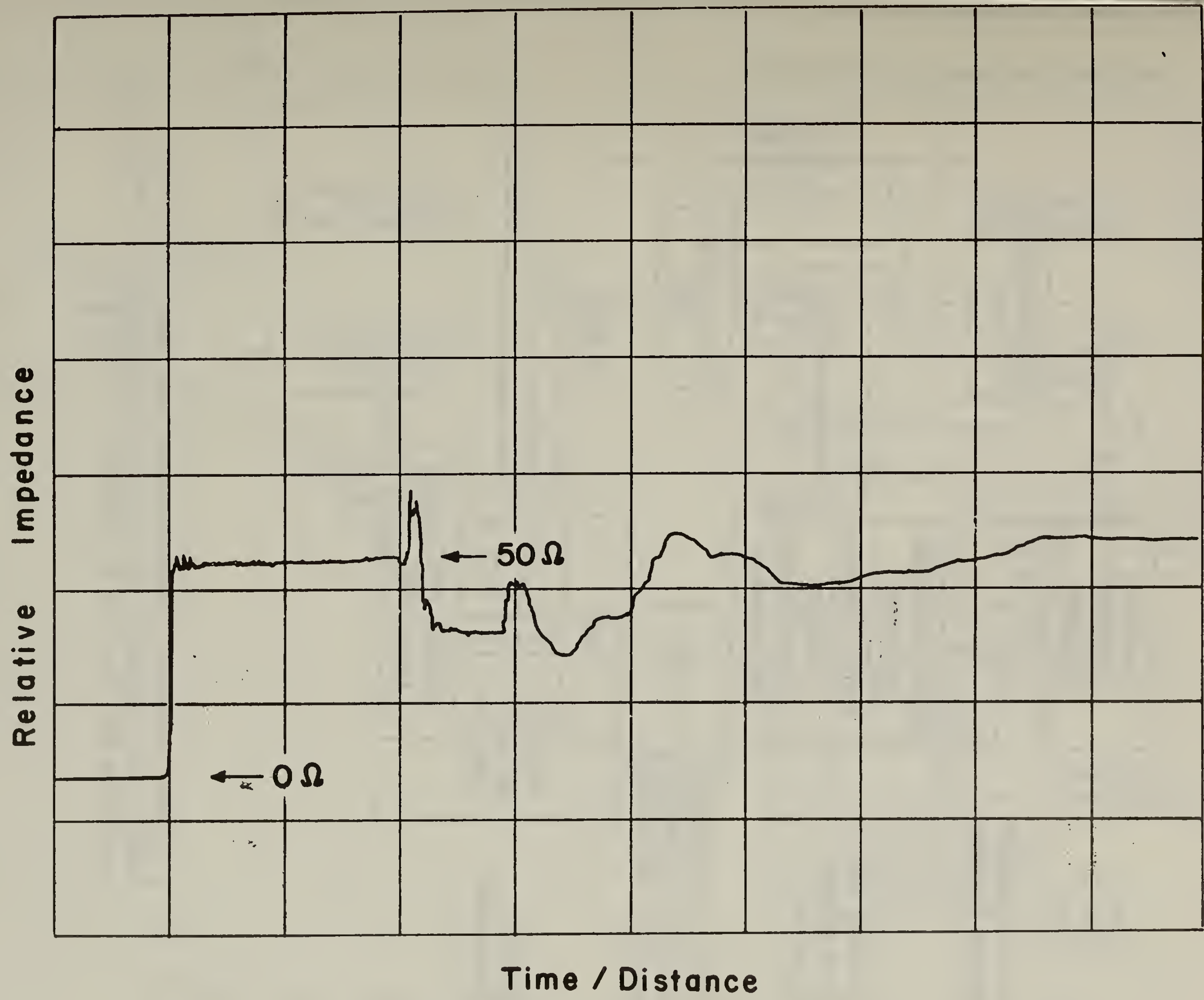


Figure 57. The time domain reflectometry signature of pin-pair 1 and 1S of the PIU input in the buffered mode.

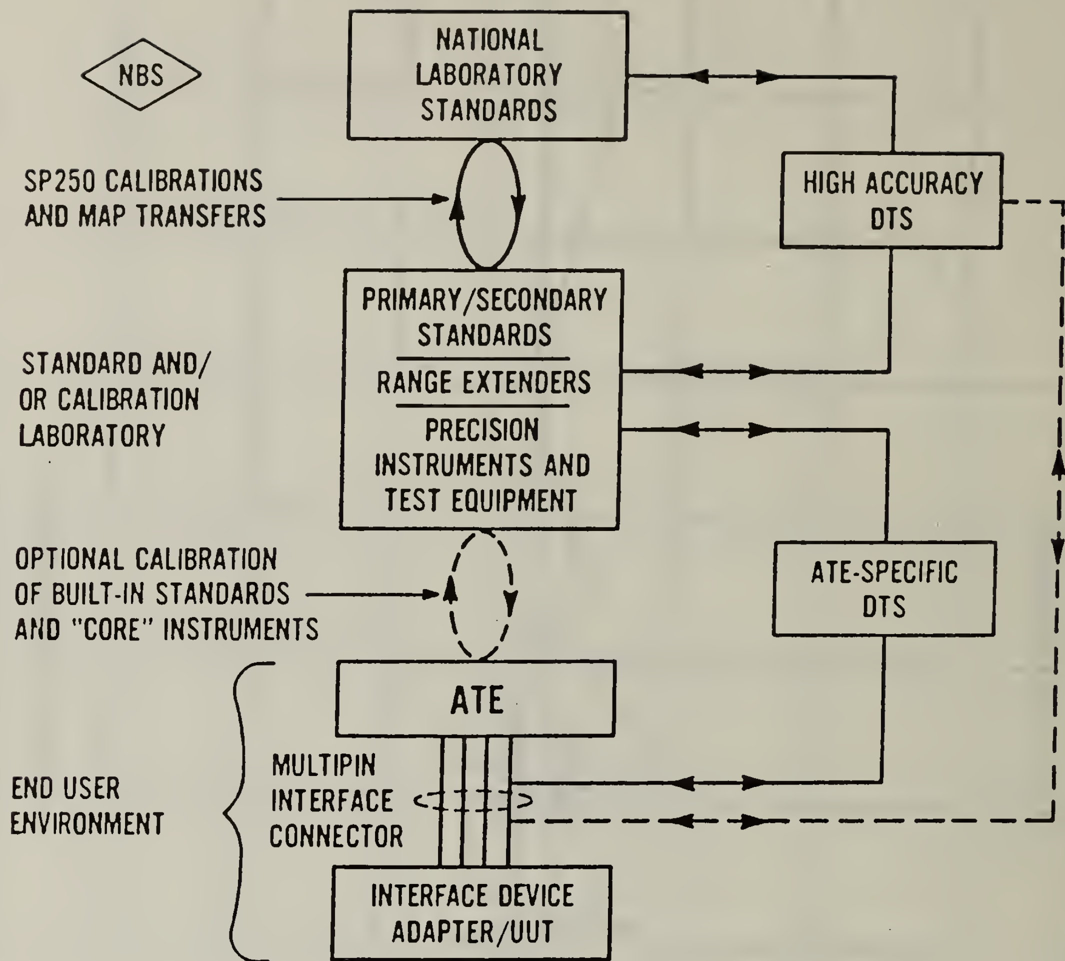


Figure 58. A Dynamic Transport Standard concept and support strategy. Dashed lines indicate that the transport standard is physically moved from one location to another.

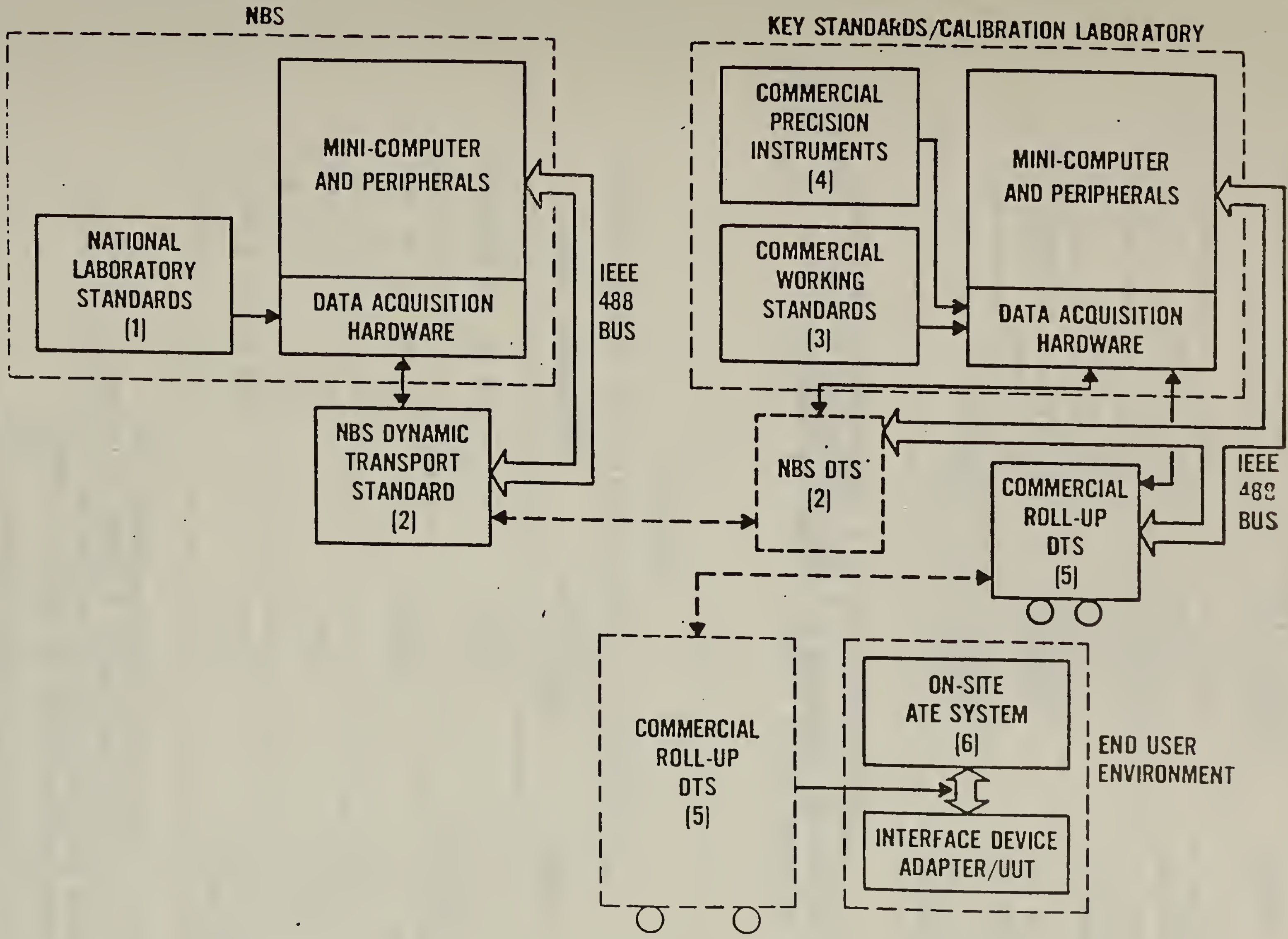


Figure 59. Dynamic Transport Standards for supplementing the present ATE calibration hierarchy.

Table 1A

Manufacturer's specification for the dc source

RANGE	RESOLUTION	RIPPLE AND NOISE
+-(20 mV to 199.999 mV)	1uV	<0.01% of setting + 25 uV rms
+-(0.2 V to 1.99999 V)	10 uV	<0.01% of setting + 25 uV rms
+-(2 V to 19.9999 V)	100 uV	<0.01% of setting + 25 uV rms
+-(20V to 199.999 V)	1 mV	<0.05% of setting

The six month accuracy for all the above ranges is:
+-(0.005% of setting + 0.001% of range + 5 uV)
over a temperature range of 20*C to 30*C.

Table 1B

Manufacturer's specification for the ac source

RANGE	RESOLUTION	FREQUENCY RANGE
0.2 to 1.99999 V	10 uV	50 Hz to 50 kHz
2 V to 19.9999 V	100 uV	50 Hz to 50 kHz
20 V to 110 V	1 mV	50 Hz to 20 kHz
110 V to 199.999 V	1 mV	50 Hz to 1 kHz

The six month amplitude accuracy is:
+-(0.05% of setting + 0.005% of range + 50 uV)
over a frequency range of 50 Hz to 10 kHz and over a temperature range of 20*C to 30*C.

The six month amplitude accuracy is:
+-(0.08% of setting + 0.008% of range + 50 uV)
over a frequency range of >10 kHz to 50 kHz and over a temperature range of 20*C to 30*C.

Table 1C

Manufacturer's specifications for the wideband source

RANGE	ACCURACY
31.62 mV to 99.999 mV	+-(0.25% of setting + 0.25% of range)
0.1 V to 0.316 V	+-(0.75% of setting + 0.25% of range)
0.316 V to 0.99999 V	+-(0.50% of setting + 0.25% of range)
1.0 V to 3.16 V	+-(0.25% of setting + 0.25% of range)

The frequency flatness over the frequency range of 1 MHz to 5 Mhz is 0.25%.
Over the frequency range of 5MHz to 10 MHz, the flatness is +- 0.6%.

Table 2. Time synthesizer calibration - data log - 50 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\bar{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\bar{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/7/81	BNC	M-M	5 ns	50.066	.013	403.71	.062	- .64	.052	
6/25/81	BNC	M-M	5 ns	50.320	.003	396.39	.17	- .91	.23	+ 0.51
4/7/81	BNC	HIST	5 ns	50.127	.012	397.19	.16	.045	.13	
6/25/81	BNC	HIST	5 ns	50.395	.003	389.47	.11	.45	.23	+ 0.54
4/7/81	ITT	M-M	5 ns	50.079	.013	401.75	.01	- .87	.16	
7/1/81	ITT	M-M	5 ns	49.875	.007	392.32	.10	-1.66	.051	- 0.41
4/7/81	ITT	HIST	5 ns	50.127	.028	396.73	2.7	- .19	.28	
7/1/81	ITT	HIST	5 ns	49.985	.035	382.72	2.2	-1.00	.13	-0.28

Table 3. Time synthesizer calibration - data log - 100 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\bar{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\bar{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/7/81	BNC	M-M	5 ns	99.758	.013	403.28	.22	- .83	.44	
6/26/81	BNC	M-M	5 ns	100.337	.014	395.35	.29	-3.39	.66	+ 0.58
4/7/81	BNC	HIST	5 ns	99.765	.012	401.50	.15	- .25	.28	
6/26/81	BNC	HIST	5 ns	100.324	.013	391.95	.020	-1.17	.83	+ 0.56
4/7/81	ITT	M-M	5 ns	99.752	.015	402.73	.19	-1.24	.37	
7/2/81	ITT	M-M	5 ns	99.637	.012	393.21	.028	-1.86	.15	- 0.12
4/7/81	ITT	HIST	5 ns	99.756	.015	401.05	.37	- .56	.19	
7/2/81	ITT	HIST	5 ns	99.639	.010	391.78	.18	-1.19	.23	- 0.12

Table 4. Time synthesizer calibration - data log - 200 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\overline{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\overline{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/8/81	BNC	M-M	50 ns	200.177	.032	403.96	.059	- 2.38	.83	
6/26/81	BNC	M-M	50 ns	199.627	.051	390.56	.15	- 1.94	.80	- 0.28
4/8/81	BNC	HIST	50 ns	200.424	.064	400.80	.058	- 1.81	.94	
6/26/81	BNC	HIST	50 ns	199.883	.085	387.61	.044	- 1.48	.80	- 0.27
4/8/81	ITT	M-M	50 ns	200.268	.027	403.41	.31	- 1.62	.22	
4/8/81	ITT	HIST	50 ns	200.279	.044	402.15	.24	- 1.05	.40	

Table 5. Time synthesizer calibration - data log - 500 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\bar{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\bar{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/8/81	BNC	M-M	50 ns	501.841	.036	412.70	.10	- 5.43	.22	
6/30/81	BNC	M-M	50 ns	499.976	.040	401.46	.023	- 4.98	.24	- 0.37
4/8/81	BNC	HIST	50 ns	503.386	.12	398.51	.12	- 4.51	.37	
6/30/81	BNC	HIST	50 ns	501.44	.033	389.33	.16	- 4.30	.062	- 0.39
4										
4/8/81	ITT	M-M	50 ns	501.815	.045	412.16	.046	- 6.00	.36	
4/8/81	ITT	HIST	50 ns	503.363	.009	398.67	.54	- 5.19	.36	

Table 6. Time synthesizer calibration - data log - special 500 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\overline{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\overline{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/9/81	BNC	M-M	5ns + F	500.595	.013	481.64	.49	-38.83	.25	
6/30/81	BNC	M-M	5ns + F	500.342	.033	464.46	.20	-36.59	.13	-0.05
4/9/81	BNC	HIST	5ns + F	500.774	.011	408.27	.14	-4.66	.24	
6/30/81	BNC	HIST	5ns + F	500.518	.026	396.18	.23	-4.59	.083	-0.05
4/9/81	ITT	M-M	5ns + F	500.750	.095	470.55	.84	-33.95	.60	
4/9/81	ITT	HIST	5ns + F	500.887	.14	409.89	2.2	-5.34	.58	

Table 7. Time synthesizer calibration - data log - 1000 ns nominal

(3 measurements per entry)

DATE	CNX	METHOD	FILTER	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	$\overline{V}_a$ (mV)	$\hat{\sigma}$ (mV)	$\overline{V}_o$ (mV)	$\hat{\sigma}$ (mV)	$\Delta\tau_D$ % NOM.
4/9/81	BNC	M-M	50 ns	999.745	.039	423.04	.35	-9.66	.85	
7/1/81	BNC	M-M	50 ns	999.648	.054	409.79	.14	-7.60	.50	-0.01
4/9/81	BNC	HIST	50 ns	----	----	----	---	----	---	2 modes @ 100%
7/1/81	BNC	HIST	50 ns	----	----	----	---	----	---	2 modes @ 100%
4/9/81	ITT	M-M		999.829	.046	423.98	.26	-9.54	.40	
4/9/81	ITT	HIST		999.784	.22	421.11	.68	-7.93	1.4	

Table 8A

DC voltage sequences used on Army EQUATE

SEQUENCE NUMBER	DC VOLTAGE
1	-.500
2	-.100
3	100.000
4	.500
5	.100
6	10.000
7	-50.000
8	-100.000
9	1.000
10	-1.000
11	-10.000
12	50.000
13	-5.000
14	5.000
15	-.500
16	-100.000
17	.100
18	.500
19	-50.000
20	10.000
21	-.100
22	5.000
23	100.000
24	1.000
25	-5.000
26	-10.000
27	-1.000
28	50.000
29	-100.000
30	-5.000
31	50.000
32	-50.000
33	.500
34	1.000
35	10.000
36	-1.000
37	100.000
38	-10.000
39	-.500
40	-.100
41	5.000
42	-.100
43	195.000
44	-195.000

Table 8B

Low-frequency voltage sequences used on Army EQUATE

SEQUENCE NUMBER	AC VOLTAGE	FREQUENCY (Hz)
1	3.000	100.0
2	.300	500.0
3	3.000	500.0
4	.300	5000.0
5	.700	2000.0
6	.700	100.0
7	.700	100.0
8	7.000	10000.0
9	.700	50.0
10	.300	50.0
11	30.000	10000.0
12	.300	10000.0
13	.300	20000.0
14	7.000	1000.0
15	.300	1000.0
16	30.000	50.0
17	7.000	500.0
18	3.000	200.0
19	30.000	5000.0
20	70.000	1000.0
21	70.000	10000.0
22	.300	100.0
23	.300	200.0
24	.700	200.0
25	7.000	200.0
26	7.000	20000.0
27	.700	1000.0
28	3.000	2000.0
29	3.000	1000.0
30	3.000	50.0
31	.700	20000.0
32	3.000	5000.0
33	3.000	10000.0
34	70.000	500.0
35	7.000	100.0
36	7.000	50000.0
37	.300	50000.0
38	.700	5000.0
39	.700	500.0
40	70.000	100.0
41	.300	2000.0
42	7.000	5000.0
43	30.000	200.0
44	7.000	2000.0
45	3.000	50000.0
46	70.000	50.0
47	70.000	2000.0
48	.700	10000.0
49	30.000	2000.0
50	30.000	20000.0
51	70.000	5000.0

Table 8B (cont.)

52	30.000	100.0
53	7.000	50.0
54	.700	50000.0
55	30.000	1000.0
56	70.000	200.0
57	30.000	500.0
58	3.000	20000.0

Table 9

Sample printout of dc data, after reduction, from Army EQUATE system

APPLIED V	MEASURED V	RATIO	ERROR PCNT
10 $			
11 $			
-.50000	-.50353	1.00705	-.7004
-.10000	-.10364	1.03641	-3.5127
100.00000	100.22868	1.00229	-.2282
.50000	.49605	.99210	.7966
.10000	.09631	.96310	3.8312
10.00000	10.00426	1.00043	-.0426
-50.00000	-49.96118	.99922	.0777
-100.00000	-100.03119	1.00031	-.0312
1.00000	.99576	.99576	.4260
-1.00000	-1.00262	1.00262	-.2614
-10.00000	-9.99590	.99959	.0410
50.00000	49.97308	.99946	.0539
-5.00000	-5.00181	1.00036	-.0362
5.00000	4.99600	.99920	.0800
-.50000	-.50332	1.00664	-.6599
-100.00000	-99.91592	.99916	.0842
.10000	.09623	.96232	3.9150
.50000	.49610	.99221	.7853
-50.00000	-49.96062	.99921	.0788
10.00000	10.00462	1.00046	-.0462
-.10000	-.10357	1.03571	-3.4479
5.00000	4.99618	.99924	.0765
100.00000	100.23994	1.00240	-.2394
1.00000	.99568	.99568	.4334
-5.00000	-5.00194	1.00039	-.0387
-10.00000	-9.99588	.99959	.0413
-1.00000	-1.00249	1.00249	-.2484
50.00000	49.97234	.99945	.0554
-100.00000	-100.01367	1.00014	-.0137
-5.00000	-5.00175	1.00035	-.0350
50.00000	49.97245	.99945	.0551
-50.00000	-49.95908	.99918	.0819
.50000	.49616	.99231	.7745
1.00000	.99572	.99572	.4300
10.00000	10.00486	1.00049	-.0486
-1.00000	-1.00266	1.00266	-.2654
100.00000	100.23750	1.00238	-.2369
-10.00000	-9.99586	.99959	.0414
-.50000	-.50340	1.00681	-.6762
-.10000	-.10359	1.03591	-3.4669
5.00000	4.99613	.99923	.0774
-.10000	-.10363	1.03629	-3.5024
195.00000	195.33877	1.00174	-.1734
-195.00000	-195.18068	1.00093	-.0926

Table 10

Sample printout of ac data, after reduction, from Army EQUATE System

APPLIED V	MEASURED V	FREQUENCY	PERCENT ERROR
3.00000	2.99754477	100.	.082
.30000	.29978985	500.	.070
3.00000	2.99758220	500.	.081
.30000	.29942834	5000.	.191
.70000	.69886835	2000.	.162
.70000	.69938251	100.	.088
.70000	.69954770	100.	.065
7.00000	7.14126986	10000.	-1.978
.70000	.69922926	50.	.110
.30000	.29963950	50.	.120
30.00000	30.70935559	10000.	-2.310
.30000	.30006786	10000.	-.023
.30000	.30002379	20000.	-.008
7.00000	7.14130872	1000.	-1.979
.30000	.29979953	1000.	.067
30.00000	30.58493733	50.	-1.913
7.00000	7.14023173	500.	-1.964
3.00000	2.99770084	200.	.077
30.00000	30.62698221	5000.	-2.047
70.00000	71.33996201	1000.	-1.878
70.00000	71.59404945	10000.	-2.227
.30000	.29977548	100.	.075
.30000	.29978710	200.	.071
.70000	.69945042	200.	.079
7.00000	7.14110744	200.	-1.976
7.00000	7.02341473	20000.	-.333
.70000	.69951895	1000.	.069
3.00000	2.99936682	2000.	.021
3.00000	2.99737918	1000.	.087
3.00000	2.99648333	50.	.117
.70000	.69940271	20000.	.085
3.00000	2.99820191	5000.	.060
3.00000	3.00513595	10000.	-.171
70.00000	71.32908630	500.	-1.863
7.00000	7.13945842	100.	-1.953
7.00000	7.66707331	50000.	-8.700
.30000	.28643311	50000.	4.736
.70000	.69859734	5000.	.201
.70000	.69963965	500.	.052
70.00000	71.34128952	100.	-1.880
.30000	.29995621	2000.	.015
7.00000	7.14309901	5000.	-2.003
30.00000	30.60174537	200.	-1.966
7.00000	7.14504111	2000.	-2.030
3.00000	2.91203383	50000.	3.021
70.00000	71.31357765	50.	-1.842
70.00000	71.28@3948	2000.	-1.806
.70000	.69992207	10000.	.011
30.00000	30.60777283	2000.	-1.986

Table 10 (cont.)

30.00000	30.94726372	20000.	-3.061
70.00000	71.38788986	5000.	-1.944
30.00000	30.59872627	100.	-1.957
7.00000	7.13741744	50.	-1.925
.70000	.69159294	50000.	1.216
30.00000	30.59998322	1000.	-1.961
70.00000	71.32343292	200.	-1.856
30.00000	30.60639238	500.	-1.981
3.00000	3.01078960	20000.	-.358

Table 11. Pulse Measurement Data, April 1981, Army EQUATE System, PIU Pins 1 and 11

NBS Pulse Duration	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\bar{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\bar{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.08	48.0			336.8			-4.8					
	52.0			330.7			-4.8					
	50.0			340.1			-4.7					
	50.0			331.3			-4.9			WC	-2.1	-4.2
	48.0	49.6	1.7	339.7	335.7	4.5	-4.7	-4.8	0.08	MEAN	-0.5	-1.0
99.75	90.0			401.5			-4.7					
	90.0			403.2			-4.8					
	92.0			403.2			-4.4					
	92.0			402.1			-4.4			WC	-9.8	-9.8
	92.0	91.2	1.1	392.5	400.5	4.5	-4.8	-4.6	0.20	MEAN	-8.6	-8.6
200.3	198.0			408.4			-4.4					
	196.0			408.4			-4.5					
	196.0			403.2			-4.4					
	198.0			403.2			-4.8			WC	-4.3	-2.1
	198.0	197.2	1.1	403.2	405.3	2.8	-4.5	-4.5	0.16	MEAN	-3.1	-1.5
501.8	490.0			440.1			-4.4					
	490.0			440.1			-4.4					
	490.0			440.1			-4.4					
	488.0			440.6			-4.3			WC	-13.8	-2.8
	490.0	489.6	0.0	444.5	441.1	1.9	-4.4	-4.4	0.04	MEAN	-12.2	-2.4
500.8	488.0			450.3			-4.4					
	490.0			450.8			-4.4					
	490.0			450.8			-4.6					
	490.0			450.8			-4.4			WC	-12.8	-2.6
	492.0	490.0	1.4	447.7	450.1	1.3	-4.4	-4.4	0.09	MEAN	-10.8	-2.2
999.8	988.0			461.5			-4.0					
	988.0			461.5			-4.2					
	988.0			461.5			-4.3					
	988.0			461.5			-4.9			WC	-11.8	-1.2
	988.0	988.0	0	456.0	459.7	2.5	-4.3	-4.1	0.18	MEAN	-11.8	-1.2

Table 12. Pulse Measurement Data, April 1981, Army EQUATE System, PIU Pins 44 and 28

NBS Pulse Duration	τ_D (ns)	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\overline{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\overline{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.08	4.0			345.0			-4.4					
	44.0			350.1			-4.3					
	44.0			348.5			-4.4					
	44.0			350.1			-4.2			WC	-6.1	-12.1
	44.0	44.0	0	345.8	347.9	2.4	-4.3	-4.3	0.08	MEAN	-6.1	-12.1
99.75	88.0			403.2			-4.4					
	92.0			394.6			-4.3					
	92.0			403.2			-3.9					
	92.0			403.2			-4.4			WC	-11.8	
	92.0	91.2	1.8	403.2	401.5	3.8	-4.4	-4.3	0.22	MEAN	- 8.6	-8.6
200.3	194.0			419.0			-4.2					
	194.0			413.5			-4.3					
	194.0			413.5			-4.4					
	196.0			415.2			-3.9			WC	-6.3	-3.1
	196.0	194.8	1.1	414.6	415.2	2.3	-4.3	-4.2	0.19	MEAN	-5.5	-2.7
501.8	488.0			445.6			-3.9					
	490.0			445.6			-3.9					
	488.0			445.6			-4.0					
	488.0			446.1			-3.9			WC	-13.8	-2.8
	490.0	488.8	1.1	445.6	445.7	0.2	-4.0	-3.9	0.05	MEAN	-13.0	-2.6
500.8	490.0			448.2			-4.2					
	490.0			449.7			-4.3					
	490.0			445.6			-4.4					
	490.0			450.8			-4.4			WC	-10.8	-2.2
	490.0	490.0	0	450.8	449.0	2.2	-4.3	-4.3	0.08	MEAN	-10.8	-2.2
999.8	988.0			462.0			-3.9					
	988.0			463.5			-3.7					
	990.0			457.6			-3.9					
	990.0			456.0			-3.8			WC	-11.8	-1.[illegible]
	988.0	988.0	1.1	461.5	460.1	3.2	-3.9	-3.8	0.09	MEAN	-11.0	-1.[illegible]

Table 13. Pulse Measurement Data, April 1981, Army EQUATE System, PIU Pins 120 and 92

NBS Pulse Duration	τ_D (ns)	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\overline{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\overline{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.08	50.0			323.0			-4.0					
	52.0			317.0			-3.9					
	50.0			321.4			-3.9					
	52.0			319.7			-3.9		0.22	WC	1.9	3.8
	50.0	50.8	.1	314.2	319.1	3.5	-4.4	-4.0		MEAN	0.8	1.4
99.75	92.0			397.7			-3.9					
	92.0			392.5			-4.0					
	92.0			397.7			-3.9					
	94.0			397.7			-4.4			WC	-7.8	-7.8
	92.0	92.4	0.9	397.7	396.7	2.3	-3.9	-4.0	0.22	MEAN	-7.4	-7.4
200.3	198.0			397.7			-3.9					
	200.0			397.7			-3.9					
	200.0			397.7			-4.3					
	200.0			398.2			-3.9			WC	-2.3	-1.1
	200.0	199.6	0.9	400.4	398.3	1.2	-3.9	-4.0	0.18	MEAN	-0.7	-0.3
501.8	492.0			434.9			-3.9					
	492.0			434.9			-3.8					
	494.0			434.9			-3.8					
	492.0			434.9			-3.9			WC	-9.8	-2.0
	492.0	492.4	0.9	434.9	434.9	0	-3.9	-3.9	0.05	MEAN	-9.4	-1.9
500.8	490.0			400.1			-3.9					
	492.0			434.9			-3.5					
	492.0			400.1			-3.9					
	492.0			440.1			-3.6			WC	-10.8	-2.2
	492.0	491.6	0.9	400.1	439.1	2.3	-3.7	-3.7	0.18	MEAN	- 9.2	-1.8
999.8	990.0			450.8			-3.5					
	990.0			450.8			-3.4					
	990.0			450.8			-3.4					
	992.0			450.8			-3.4			WC	- 9.8	-1.0
	990.0	990.4	0.9	450.8	450.8	0	-3.4	-3.4	0.04	MEAN	- 9.4	-0.9

Table 14. Pulse Measurement Data, April 1981, Army EQUATE System, DIU BNC #1

NBS Pulse Duration	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\bar{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\bar{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.07	42.0			391.1			-3.9					
	42.0			390.8			-3.9					
	42.0			391.0			-3.9					
	42.0			389.8			-3.9			WC	-8.1	-16.1
	42.0	42.0	0	391.2	390.8	0.6	-3.9	-3.9	0	MEAN	-8.1	-16.1
99.76	92.0			397.2			-3.9					
	92.0			397.2			-3.9					
	92.0			397.2			-3.9					
	92.0			396.9			-3.9			WC	-7.8	- 7.8
	92.0	92.0	0	397.2	397.1	0.1	-3.9	-3.9	0	MEAN	-7.8	- 7.8
200.2	196.0			394.7			-3.9					
	196.0			394.7			-3.9					
	196.0			394.9			-3.7					
	198.0			394.4			-3.9			WC	-4.2	- 2.1
	198.0	196.8	1.1	394.4	394.4	0.2	-3.9	-3.9	0.09	MEAN	-3.4	- 1.7
501.8	496.0			403.6			-3.6					
	496.0			403.3			-3.5					
	498.0			403.4			-3.6					
	498.0			4.03			-3.5			WC	-5.8	- 1.2
	498.0	497.2	1.1	403.5	403.4	0.1	-3.9	-3.6	0.16	MEAN	-4.6	- 0.9
500.6	494.0			407.0			-3.9					
	494.0			407.0			-3.9					
	494.0			406.9			-3.9					
	494.0			407.0			-3.9			WC	-6.6	- 1.3
	494.0	494.0	0	407.1	407.0	0.1	-3.9	-3.9	0	MEAN	-6.6	- 1.3
999.7	998.0			408.0			-3.9					
	998.0			408.0			-3.7					
	996.0			408.0			-3.4					
	998.0			408.0			-3.9			WC	-3.7	-0.4
	998.0	997.6	0.0	408.0	408.0	0	-3.9	-3.8	0.22	MEAN	-2.1	-0.2

Table 15. Pulse Measurement Data, April 1981, Army EQUATE System, DIU BNC #2

NBS Pulse Duration	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\bar{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\bar{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.07	42.0			398.8			-3.9					
	42.0			390.8			-3.9					
	42.0			391.0			-3.9					
	42.0			392.0			-3.9			WC	-8.1	-16.1
	42.0	42.0	0	390.5	390.8	0.8	-3.9	-3.9	0	MEAN	-8.1	-16.1
99.76	92.0			397.2			-3.9					
	92.0			397.2			-3.9					
	92.0			397.2			-3.9					
	92.0			396.9			-3.9			WC	-7.8	- 7.8
	94.0	92.4	0.9	397.2	397.2	0	-3.9	-3.9	0	MEAN	-7.4	- 7.4
200.2	198.0			394.4			-3.9					
	198.0			394.9			-3.9					
	196.0			394.6			-3.7					
	196.0			394.4			-3.9			WC	-4.2	- 2.1
	198.0	197.2	1.1	394.5	394.6	0.2	-3.9	-3.9	0	MEAN	-3.0	- 1.7
501.8	498.0			403.3			-3.8					
	498.0			403.2			-3.9					
	496.0			403.0			-3.9					
	498.0			403.3			-3.9			WC	-5.8	- 1.2
	498.0	497.2	1.1	402.9	403.1	0.2	-3.4	-3.8	0.22	MEAN	-4.6	- 0.9
500.6	494.0			406.1			-3.9					
	494.0			406.2			-3.9					
	494.0			406.1			-3.9					
	494.0			406.1			-3.9			WC	-6.6	- 1.3
	496.0	494.4	0.9	406.1	406.1	0	-3.9	-3.9	0	MEAN	-6.2	- 1.2
999.7	996.0			406.9			-3.8					
	998.0			407.0			-3.4					
	996.0			406.7			-3.7					
	996.0			406.6			-3.5			WC	-3.7	-0.4
	998.0	996.8	1.1	406.8	406.8	0.2	-3.4	-3.6	0.18	MEAN	-2.9	-0.3

Table 16. Pulse Measurement Data, April 1981, Army EQUATE System, DIU BNC #4

NBS Pulse Duration	τ_D (ns)	$\overline{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (mV)	$\overline{V}_{MAX}$ (mV)	$\hat{\sigma}$ (mV)	V_{MIN} (mV)	$\overline{V}_{MIN}$ (mV)	$\hat{\sigma}$	WC = WORST CASE	$\Delta\tau$ (ns)	$\Delta\tau$ (%)
50.07	42.0			389.2			-3.9					
	42.0			390.1			-3.9					
	42.0			389.7			-3.9					
	42.0			389.7			-3.9			WC	-8.1	-16.1
	42.0	42.0	0	390.3	389.8	0.4	-3.9	-3.9	0	MEAN	-8.1	-16.1
99.76	92.0			395.8			-3.9					
	92.0			395.8			-3.9					
	92.0			395.8			-3.9					
	92.0			395.8			-3.9			WC	-7.8	- 7.8
	92.0	92.4	0.9	396.1			-3.9	-3.9	0	MEAN	-7.4	-7.4
200.2	198.0			395.6			-3.9					
	198.0			395.4			-3.9					
	198.0			395.1			-3.9					
	198.0			395.3			-3.9			WC	-2.2	- 1.1
	198.0	198.0	0	395.9	395.3	0.3	-3.9	-3.9	0	MEAN	-2.2	- 1.1
501.8	496.0			403.8			-3.9					
	498.0			403.6			-3.9					
	496.0			403.3			-3.9					
	498.0			403.3			-3.9			WC	-5.8	- 1.2
	498.0	496.8	1.1	403.3	403.5	0.2	-3.4	-3.8	0.04	MEAN	-5.0	- 1.0
500.6	494.0			406.6			-3.9					
	494.0			406.9			-3.9					
	494.0			407.0			-3.9					
	494.0			406.7			-3.9			WC	-6.6	- 1.3
	494.0	494.0	0	407.0	406.8	0.2	-3.9	-3.9	0	MEAN	-6.6	- 1.3
999.7	998.0			408.0			-3.8					
	998.0			408.0			-3.9					
	998.0			408.0			-3.5					
	998.0			408.0			-3.7			WC	-2.1	-0.2
	998.0	997.6	0.9	408.0	408.0	0	-3.6	-3.7	0.16	MEAN	-2.1	-0.2

Table 17A

DC voltage sequence used on Navy EQUATE

SEQUENCE NUMBER	DC VOLTAGE
1	-.500
2	-.100
3	100.000
4	.500
5	.100
6	10.000
7	-50.000
8	195.000
9	-100.000
10	-195.000
11	1.000
12	-1.000
13	-10.000
14	50.000
15	-5.000
16	5.000
17	-.500
18	-100.000
19	.100
20	.500
21	-50.000
22	10.000
23	-.100
24	5.000
25	100.000
26	-195.000
27	1.000
28	-5.000
29	-10.000
30	-1.000
31	195.000
32	50.000
33	-100.000
34	-5.000
35	195.000
36	50.000
37	-50.000
38	.500
39	1.000
40	10.000
41	-1.000
42	100.000
43	-10.000
44	-.500
45	-195.000
46	-.100
47	5.000
48	-.100

Table 17B

Low-frequency voltage sequence used on Navy EQUATE

SEQUENCE NUMBER	AC VOLTAGE		FREQUENCY (Hz)
1	3.000	@	100.0
2	.300		500.0
3	3.000		500.0
4	.300		5000.0
5	.700		2000.0
6	130.000		500.0
7	.700		100.0
8	130.000		50.0
9	7.000		10000.0
10	.700		50.0
11	.300		50.0
12	30.000		10000.0
13	.300		10000.0
14	.300		20000.0
15	7.000		1000.0
16	.300		1000.0
17	30.000		50.0
18	7.000		500.0
19	3.000		200.0
20	30.000		5000.0
21	130.000		100.0
22	70.000		1000.0
23	70.000		10000.0
24	.300		100.0
25	.300		200.0
26	.700		200.0
27	7.000		200.0
28	7.000		20000.0
29	.700		1000.0
30	3.000		2000.0
31	3.000		1000.0
32	3.000		50.0
33	130.000		200.0
34	.700		20000.0
35	3.000		5000.0
36	3.000		10000.0
37	70.000		500.0
38	7.000		100.0
39	7.000		50000.0
40	.300		50000.0
41	.700		5000.0
42	.700		500.0
43	70.000		100.0
44	130.000		1000.0
45	.300		2000.0
46	7.000		5000.0
47	30.000		200.0
48	7.000		2000.0
49	3.000		50000.0
50	70.000		50.0

Table 17C

High-frequency voltage sequence used on Navy EQUATE

SEQUENCE NUMBER	AC VOLTAGE	FREQUENCY (MHz)
1	3.000	.06
2	2.000	.06
3	1.000	.06
4	.500	.06
5	.250	.06
6	.100	.06
7	.050	.06
8	3.000	.1
9	2.000	.1
10	1.000	.1
11	.500	.1
12	.250	.1
13	.100	.1
14	.050	.1
15	3.000	.2
16	2.000	.2
17	1.000	.2
18	.500	.2
19	.250	.2
20	.100	.2
21	.050	.2
22	3.000	.5
23	2.000	.5
24	1.000	.5
25	.500	.5
26	.250	.5
27	.100	.5
28	.050	.5
29	3.000	1.0
30	2.000	1.0
31	1.000	1.0
32	.500	1.0
33	.250	1.0
34	.100	1.0
35	.050	1.0
36	3.000	2.0
37	2.000	2.0
38	1.000	2.0
39	.500	2.0
40	.250	2.0
41	.100	2.0
42	.050	2.0
43	3.000	5.0
44	2.000	5.0
45	1.000	5.0
46	.500	5.0
47	.250	5.0
48	.100	5.0
49	.050	5.0
50	3.000	10.0

Table 17C (cont.)

51	70.000	2000.0
52	.700	10000.0
53	30.000	2000.0
54	30.000	20000.0
55	70.000	5000.0
56	30.000	100.0
57	7.000	50.0
58	.700	50000.0
59	30.000	1000.0
60	70.000	200.0
61	30.000	500.0
62	3.000	20000.0

Table 18

Sample printout of dc data, after reduction, from Navy EQUATE System

	APPLIED V	MEASURED V	RATIO	ERROR PCNT
1 $				
2 $				
	-.50000	-.49989	.99978	.0220
	-.10000	-.10016	1.00156	-.1560
	100.00000	-99.87885	-.99879	-200.1213
	.50000	.49978	.99956	.0438
	.10000	.09989	.99890	.1100
	10.00000	.38007	.03801	2531.0803
	-50.00000	-50.11979	1.00240	-.2390
	195.00000	195.05390	1.00028	-.0276
	-100.00000	-100.60526	1.00605	-.6016
	-195.00000	-195.91589	1.00470	-.4675
	1.00000	.98523	.98523	1.4996
	-1.00000	-1.00070	1.00070	-.0699
	-10.00000	-10.05379	1.00538	-.5350
	50.00000	50.03954	1.00079	-.0790
	-5.00000	-4.99989	.99998	.0022
	5.00000	5.00008	1.00002	-.0016
	-.50000	-.49988	.99976	.0242
	-100.00000	-100.62125	1.00621	-.6174
	.10000	.09987	.99872	.1282
	.50000	.49979	.99959	.0412
	-50.00000	-50.12015	1.00240	-.2397
	10.00000	-2.73949	-.27395	-465.0313
	-.10000	-.10017	1.00174	-.1733
	5.00000	5.00005	1.00001	-.0009
	100.00000	-99.88494	-.99885	-200.1152
	-195.00000	-195.93347	1.00479	-.4764
	1.00000	.99720	.99720	.2810
	-5.00000	-4.99997	.99999	.0006
	-10.00000	-10.05426	1.00543	-.5397
	-1.00000	-1.00090	1.00090	-.0900
	195.00000	195.04376	1.00022	-.0224
	50.00000	50.03855	1.00077	-.0770
	-100.00000	-100.61283	1.00613	-.6091
	-5.00000	-4.99997	.99999	.0005
	195.00000	195.04230	1.00022	-.0217
	50.00000	50.03983	1.00080	-.0796
	-50.00000	-50.12116	1.00242	-.2417
	.50000	.49976	.99951	.0485
	1.00000	.98722	.98722	1.2949
	10.00000	-1.19966	-.11997	-933.5708
	-1.00000	-1.00082	1.00082	-.0815
	100.00000	-99.87959	-.99880	-200.1205
	-10.00000	-10.05437	1.00544	-.5408
	-.50000	-.49992	.99983	.0168
	-195.00000	-195.92321	1.00473	-.4712
	-.10000	-.10020	1.00202	-.2011
	5.00000	5.00006	1.00001	-.0012
	-.10000	-.10018	1.00183	-.1827

Table 18 (cont.)

51	2.000	10.0
52	1.000	10.0
53	.500	10.0
54	.250	10.0
55	.100	10.0
56	.050	10.0

Table 19

Sample printout of ac data, after reduction, from Navy EQUATE System

APPLIED V	MEASURED V	FREQUENCY	PERCENT ERROR
3.00000	2.99749321	100.	.084
.30000	.29962707	500.	.124
3.00000	2.99595791	500.	.135
.30000	.29968399	5000.	.105
.70000	.70007627	2000.	-.011
130.00000	129.90096283	500.	.076
.70000	.69853035	100.	.210
130.00000	129.85685921	50.	.110
7.00000	7.00621760	10000.	-.089
.70000	.69894625	50.	.151
.30000	.29950634	50.	.165
30.00000	30.01687121	10000.	-.056
.30000	.29966037	10000.	.113
.30000	.29881605	20000.	.396
7.00000	7.00114870	1000.	-.016
.30000	.29959688	1000.	.135
30.00000	29.96718860	50.	.109
7.00000	6.99205047	500.	.114
3.00000	2.99603948	200.	.132
30.00000	30.00501728	5000.	-.017
130.00000	130.26374817	100.	-.202
70.00000	70.04798126	1000.	-.068
70.00000	70.06575298	10000.	-.094
.30000	.29950970	100.	.164
.30000	.29969211	200.	.103
.70000	.70029834	200.	-.043
7.00000	6.99423301	200.	.082
7.00000	7.04134464	20000.	-.587
.70000	.70003940	1000.	-.006
3.00000	3.00114509	2000.	-.038
3.00000	2.99892226	1000.	.036
3.00000	2.99920934	50.	.026
130.00000	129.87790489	200.	.094
.70000	.69875751	20000.	.178
3.00000	3.00000489	5000.	.000
3.00000	3.00285837	10000.	-.095
70.00000	70.02282143	500.	-.033
7.00000	7.00811309	100.	-.116
7.00000	10.81865954	50000.	-35.297
.30000	.29167969	50000.	2.853
.70000	.69953442	5000.	.067
.70000	.69892873	500.	.153
70.00000	70.17725468	100.	-.253
130.00000	130.05159950	1000.	-.040
.30000	.29982820	2000.	.057
7.00000	6.98962283	5000.	.148
30.00000	29.98130941	200.	.062
7.00000	6.98997414	2000.	.143
3.00000	3.04289860	50000.	-1.410

Table 19 (cont.)

70.00000	69.94927979	50.	.073
70.00000	69.97371101	2000.	.038
.70000	.69948499	10000.	.074
30.00000	29.96436715	2000.	.119
30.00000	30.13189340	20000.	-.438
70.00000	69.99487686	5000.	.007
30.00000	30.00201583	100.	-.007
7.00000	6.99351937	50.	.093
.70000	.68329054	50000.	2.445
30.00000	30.02652526	1000.	-.088
70.00000	70.05647278	200.	-.081
30.00000	30.01932883	500.	-.064
3.00000	3.01345593	20000.	-.447

Table 20. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 1 and 1S, unbuffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	46.10			1.344			.00213					
	45.00			1.429			.00213					
	44.40			1.455			.00213					
	45.00			1.423			.00213			WC	- 5.7	-11.3
	44.90	45.1	0.6	1.439	1.418	0.04	.00213	.00213	0	MEAN	- 5.0	- 9.9
99.75	112.00			1.698			.00213					
	100.00			1.847			.00213					
	111.00			1.708			.00213					
	112.00			1.716			.00213			WC	12.3	12.3
	109.00	108.8	5.1	1.833	1.760	0.07	.00213	.00213	0	MEAN	9.1	9.1
200.3	192.0			1.995			.00213					
	194.00			1.905			.00213					
	192.0			1.955			.00213					
	190.0			2.034			.00213			WC	-10.3	- 5.1
	195.0	192.6	1.9	1.882	1.954	0.06	.00213	.00213	0	MEAN	- 7.7	- 3.8
501.8	492.0			2.273			.00213					
	492.0			2.237			.00213					
	495.0			2.181			.00213					
	491.0			2.251			.00213			WC	-11.8	- 2.4
	490.0	492.0	1.9	2.297	2.248	0.04	.00213	.00213		MEAN	- 9.8	- 2.0
999.8	988.0			2.390			.00262					
	988.0			2.370			.00457					
	988.0			2.399			.00457					
	987.0			2.409			.00457			WC	-13.8	- 1.4
	986.0	987.4	0.9	2.432	2.400	0.02	.00457	.00418	.0008	MEAN	-12.4	- 1.2

Table 21. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 1 and 1S, buffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	47.70			2.705			.00457					
	49.90			2.473			.01159					
	46.10			2.871			.01159					
	46.30			2.859			.01159			WC	-4.0	-7.9
	48.80	47.8	1.6	2.660	2.714	0.16	.01159	.01019	.0031	MEAN	-2.3	-4.6
99.75	99.40			2.817			.01049					
	97.40			2.894			.01159					
	99.20			2.854			.01159					
	98.90			2.853			.01159			WC	-2.4	-2.4
	98.30	98.6	0.8	2.854	2.854	0.03	.01159	.01137	.0005	MEAN	-1.2	-1.2
200.3	197.0			2.727			.01159					
	195.0			2.763			.01159					
	195.0			2.754			.01159					
	195.0			2.730			.01159			WC	-5.3	-2.6
	197.0	195.8	1.1	2.707	2.736	0.02	.00964	.01120	.0009	MEAN	-4.5	-2.2
501.8	495.0			2.750			.00457					
	497.0			2.700			.00457					
	501.0			2.439			.00457					
	497.0			2.709			.00457			WC	-6.8	-1.4
	495.0	497.0	2.4	2.703	2.660	0.13	.00457	.00457	0	MEAN	-4.8	-1.0
999.8	995.0			2.747			.00213					
	996.0			2.710			.00213					
	997.0			2.701			.00213					
	995.0			2.716			.00213			WC	-4.8	-0.5
	995.0	995.6	0.9	2.711	2.717	0.02	.00213	.00213	-	MEAN	-4.2	-0.4

Table 22. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 19 and 19S, unbuffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	43.80			1.491			.00286					
	46.70			1.281			.00213					
	44.70			1.405			.00213					
	46.10			1.298			.00213			WC	- 6.3	-12.5
	45.10	45.3	1.1	1.390	1.373	0.09	.00213	.00228	.0003	MEAN	-4.8	- 9.5
99.75	107.0			1.815			.00238					
	107.0			1.805			.00286					
	99.0			1.871			.00286					
	92.4			1.879			.00213			WC	- 7.4	- 7.4
	107.0	102.5	6.6	1.812	1.836	0.04	.00213	.00247	.0004	MEAN	2.8	2.8
200.3	198.0			1.796			.00408					
	188.0			2.072			.00238					
	189.0			2.024			.00213					
	195.0			1.880			.00457			WC	-12.3	- 6.1
	192.0	192.4	4.2	1.967	1.948	0.11	.00213	.00306	.0012	MEAN	- 7.9	- 3.9
501.8	492.0			2.209			.00457					
	489.0			2.291			.00457					
	492.0			2.193			.00457					
	492.0			2.226			.00433			WC	-12.8	- 2.6
	492.0	491.4	1.3	2.204	2.225	0.04	.00457	.00452	.0001	MEAN	-10.4	- 2.1
999.8	988.0			2.397			.00457					
	987.0			2.410			.00457					
	989.0			2.378			.00457					
	987.0			2.393			.00457			WC	-12.8	- 1.3
	988.0	987.8	0.8	2.389	2.393	0.01	.00457	.00457	0	MEAN	-12.0	- 1.2

Table 23. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 19 and 19S, buffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	46.10			2.667			.01159					
	47.30			2.559			.01159					
	45.40			2.741			.01159					
	45.50			2.709			.01159			WC	-4.7	-9.3
	45.70	46.0	0.8	2.689	2.673	0.07	.01150	.01159	0	MEAN	-4.1	-8.1
99.75	97.40			2.698			.00717					
	97.60			2.662			.01159					
	97.00			2.726			.00717					
	97.50			2.663			.01086			WC	-2.8	-2.8
	97.70	97.4	0.3	2.683	2.686	0.03	.00912	.00918	.0020	MEAN	-2.4	-2.4
200.3	196.0			2.567			.01123					
	195.0			2.578			.00790					
	197.0			2.542			.00457					
	196.0			2.551			.00509			WC	-5.3	-2.6
	195.0	195.8	0.8	2.588	2.565	0.02	.00805	.00737	.0027	MEAN	-4.5	-2.2
501.8	495.0			2.578			.00457					
	495.0			2.590			.00457					
	495.0			2.580			.00457					
	495.0			2.576			.00457			WC	-6.8	-1.4
	496.0	495.2	0.4	2.580	2.581	0.01	.00457	.00457	0	MEAN	-6.6	-1.3
999.8	995.0			2.597			.00408					
	994.0			2.604			.00457					
	995.0			2.601			.00457					
	995.0			2.605			.00335			WC	-5.8	-0.6
	995.0	994.8	0.4	2.599	2.601	0.003	.00213	.00374	.0010	MEAN	-5.0	-0.5

Table 24. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 58 and 58S, unbuffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	46.30			1.286			.00457					
	42.30			1.535			.00433					
	43.00			1.458			.00238					
	45.30			1.331			.00213			WC	- 7.8	-15.5
	43.40	44.1	1.7	1.447	1.411	0.10	.00213	.00311	.0012	MEAN	- 6.0	-11.9
99.75	107.0			1.841			.00213					
	93.6			1.825			.00213					
	94.6			1.810			.00457					
	93.4			1.827			.00384			WC	- 9.3	- 9.3
	109.0	99.5	7.8	1.752	1.811	0.03	.00286	.00311	.0011	MEAN	- 0.3	- 0.3
200.3	196.0			1.869			.00360					
	196.0			1.857			.00213					
	192.0			1.962			.00457					
	198.0			1.816			.00213			WC	- 8.3	- 4.1
	197.0	195.8	2.3	1.850	1.871	0.05	.00213	.00291	.0011	MEAN	- 4.5	- 2.2
501.8	489.0			2.367			.00335					
	495.0			2.176			.00457					
	493.0			2.250			.00457					
	490.0			2.311			.00457			WC	-12.8	- 2.6
	499.0	493.2	4.0	2.059	2.233	0.12	.00457	.00433	.0005	MEAN	- 8.6	- 1.7
999.8	990.0			2.360			.00457					
	988.0			2.411			.00457					
	989.0			2.378			.00457					
	988.0			2.407			.00457			WC	-12.8	- 1.3
	987.0	988.4	1.1	2.428	2.397	0.03	.00457	.00457	0	MEAN	-11.4	- 1.1

Table 25. Pulse Measurement Data, July 1981, Navy EQUATE System, PIU Pins 58 and 58S, buffered

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.08	48.50			2.676			.00457					
	48.40			2.726			.00457					
	48.80			2.625			.00457					
	48.60			2.680			.00457			WC	-1.8	-3.6
	48.30	48.5	0.2	2.686	2.679	0.04	.00457	.00457	0	MEAN	-1.6	-3.2
99.75	101.0			2.616			.00457					
	100.0			2.753			.00457					
	101.0			2.614			.00457					
	100.0			2.749			.00457			WC	1.3	1.3
	100.0	100.4	0.5	2.664	2.679	0.07	.00457	.00457	0	MEAN	0.7	0.7
200.3	195.0			2.604			.00457					
	195.0			2.608			.00457					
	196.0			2.586			.00457					
	195.0			2.597			.00457			WC	-5.3	-2.6
	196.0	195.4	0.5	2.593	2.598	0.01	.00457	.00457	0	MEAN	-4.9	-2.4
501.8	495.0			2.622			.00213					
	495.0			2.615			.00311					
	495.0			2.612			.00213					
	501.0			2.345			.00360			WC	-6.8	-1.4
	496.0	496.4	2.6	2.603	2.559	0.12	.00213	.00262	.0007	MEAN	-5.4	-1.1
999.8	995.0			2.613			.00213					
	995.0			2.623			.00213					
	995.0			2.628			.00213					
	996.0			2.620			.00213			WC	-4.8	-0.5
	995.0	995.0	0.4	2.623	2.621	0.01	.00213	.00213	0	MEAN	-4.6	-0.5

Table 26. Pulse Measurement Data, July 1981, Navy EQUATE System, DIU BNC #1 using various pulse durations

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
50.07	50.00			2.354			.00274					
	49.30			2.360			.00274					
	49.20			2.368			.00274					
	49.50			2.330			.00274			WC	- 1.0	- 1.9
	49.10	49.4	0.4	2.359	2.354	0.01	.00274	.00274	0	MEAN	- 0.7	- 1.3
99.76	99.90			2.364			.00274					
	99.80			2.388			.00274					
	99.70			2.411			.00274					
	99.90			2.400			.00274			WC	0.1	0.1
	99.90	99.8	0.1	2.381	2.389	0.02	.00274	.00274	0	MEAN	0.04	0.04
200.2	190.0			2.374			.00274					
	192.0			2.308			.00274					
	192.0			2.306			.00274					
	191.0			2.365			.00274			WC	-10.2	- 5.1
	192.0	191.4	0.9	2.315	2.334	0.03	.00274	.00274	0	MEAN	- 8.8	- 4.4
501.8	491.0			2.415			.00274					
	491.0			2.413			.00274					
	491.0			2.414			.00274					
	491.0			2.412			.00274			WC	-10.8	- 2.2
	491.0	491.0	0	2.407	2.412	0.03	.00274	.00274	0	MEAN	-10.8	- 2.2
999.7	991.0			2.446			.00274					
(DC=10%)	991.0			2.458			.00274					
	991.0			2.452			.00274					
	991.0			2.454			.00274			WC	- 8.7	- 0.9
	992.0	991.2	0.4	2.435	2.449	0.01	.00274	.00274	0	MEAN	- 8.5	- 0.9

Table 27. Pulse Measurement Data, July 1981, Navy EQUATE System, DIU BNC #1 using various pulse durations

NBS PULSE DURATION	τ_D (ns)	$\bar{\tau}_D$ (ns)	$\hat{\sigma}$ (ns)	V_{MAX} (V)	$\bar{V}_{MAX}$ (V)	$\hat{\sigma}$ (V)	V_{MIN} (V)	$\bar{V}_{MIN}$ (V)	$\hat{\sigma}$ (V)	WC = WORST CASE	$\Delta\tau_D$ (ns)	$\Delta\tau_D$ (%)
999.7	990.0			2.514			.00274					
(DC=1%)	990.0			2.508			.00274					
	990.0			2.508			.00274					
	990.0			2.508			.00274			WC	-10.7	- 1.1
	989.0	989.8	0.4	2.508	2.509	.003	.00274	.00274	0	MEAN	- 9.9	- 1.0
999.7	989.0			2.531			.00274					
(DC=0.2%)	989.0			2.533			.00274					
	990.0			2.527			.00274					
	990.0			2.527			.00274			WC	-10.7	- 1.1
	990.0	989.6	0.5	2.529	2.529	.003	.00274	.00274	0	MEAN	-10.1	- 1.0

APPENDIX A

Listing of the ATLAS program DCV, ACVL, and ACVH run on the Army EQUATE System

```
C     BEGIN PROGRAM TO TEST DC-CALIBRATION OF EQUATE$
C     BY T.LEEDY N.B.S. 4/21/81$

      DECLARE DECIMAL, 'VDC', 'VMAX'$
      DECLARE DECIMAL, 'STEP', MAXSTP', 'TPHI', 'TPLO'$
      DEFINE 'LINE', RECORD " "$


E   5 'LINE'$
      SELECT PIU$

      DISPLAY, "*******************************************
                * THIS PROGRAM WILL MEASURE THE D.C. VOLTAGE *
                * AT THE P.I.U. INPUTS <TPHI> AND <TPLO>     *
                * (ASSURE THAT THE SWITCH ON THE ADAPTER IS  *
                *      SET TO THE LF/DC POSITION)
                *     PRESS <PROCEED> TO CONTINUE            *
                *******************************************"$
      WAIT-FOR MANUAL-INTERVENTION$


   10 'LINE'$
      DISPLAY, "ENTER NUMBER OF STEPS DESIRED"$
      DISPLAY, "MAXIMUM NUMBER OF STEPS IS 48"$
      INPUT 'MAXSTP'$
      'LINE'$
      RECORD, "***** PARAMETERS OF TEST *****"$
      'LINE'$
      RECORD,'MAXSTP', "NUMBER OF STEPS =#.STEPS"$

   20 'STEP'= 1$
      DISPLAY, "ENTER P.I.U. PINS UNDER TEST -- TPHI AND TPLO"$
      INPUT 'TPHI'$
      INPUT 'TPLO'$
      RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
      RECORD, 'TPLO', "AND PIN TPLO IS NUMBER  = #."$
   30 CONNECT EARTH, CNX TP 128$
      CONNECT EARTH, CNX TP 'TPLO'$
      APPLY DC-SIGNAL DC2A, VOLTAGE 5V, CNX HI 127 LO 128$
      DELAY 0.01 SEC$
      REMOVE DC2A$

      DELAY 3 SEC$
      MEASURE (VOLTAGE 'VMAX' V), DC-SIGNAL,
      CNX HI 'TPHI' LO 'TPLO'$

      MEASURE (VOLTAGE 'VDC' V), DC-SIGNAL, VOLTAGE MAX 'VMAX' V,
      CNX HI 'TPHI' LO 'TPLO'$

      RECORD 'VDC',"MEASURED VOLTAGE IS = ###.####### VDC"$
      COMPARE 'STEP', GT 'MAXSTP'$
      GOTO STEP 40 IF GO$
      'STEP' = 'STEP' + 1$
      GOTO STEP 30$
```

```
   40 DISPLAY, "
              ******************************************
              *  PRESS <YES> TO SELECT NEW P.I.U. PINS  *
              *  PRESS  <NO> TO TERMINATE THIS PROGRAM  *
              ******************************************"$
      WAIT-FOR MANUAL-DATA-GO-NOGO$
      GOTO STEP 20 IF GO$
      PRINT, "!P"$
E  999 TERMINATE$
```

```
C       BEGIN PROGRAM TO TEST AC-CALIBRATION OF EQUATE$
C       IN THE LOW FREQUENCY REGION (100 HZ TO 50 KHZ)$
C       BY T.LEEDY N.B.S. 4/21/81$

        DECLARE DECIMAL, 'VAC', 'VMAX'$
        DECLARE DECIMAL, 'STEP', MAXSTP', 'TPHI', 'TPLO'$
        DEFINE 'LINE', RECORD " "$


E     5 'LINE'$
        SELECT PIU$

        DISPLAY, "*****************************************
                 * THIS PROGRAM WILL MEASURE THE A.C. VOLTAGE *
                 * AT THE P.I.U. INPUTS <TPHI> AND <TPLO>     *
                 * (ASSURE THAT THE SWITCH ON THE ADAPTER IS  *
                 *      SET TO THE LF/DC POSITION)
                 *     PRESS <PROCEED> TO CONTINUE            *
                 *******************************************"$
        WAIT-FOR MANUAL-INTERVENTION$


     10 'LINE'$
        DISPLAY, "ENTER NUMBER OF STEPS DESIRED"$
        DISPLAY, "MAXIMUM NUMBER OF STEPS IS 63"$
        INPUT 'MAXSTP'$
        'LINE'$
        RECORD, "***** PARAMETERS OF TEST *****"$
        'LINE'$
        RECORD,'MAXSTP', "NUMBER OF STEPS =#.STEPS"$

     20 'STEP'= 1$
        DISPLAY, "ENTER P.I.U. PINS UNDER TEST -- TPHI AND TPLO"$
        INPUT 'TPHI'$
        INPUT 'TPLO'$
        RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
        RECORD, 'TPLO', "AND PIN TPLO IS NUMBER  = #."$
     30 CONNECT EARTH, CNX TP 128$
        CONNECT EARTH, CNX TP 'TPLO'$
        APPLY DC-SIGNAL DC2A, VOLTAGE 5V, CNX HI 127 LO 128$
        DELAY 0.01 SEC$
        REMOVE DC2A$

        DELAY 3 SEC$
        MEASURE (VOLTAGE 'VMAX' V), AC-SIGNAL, FREQ 5000 HZ,
        CNX HI 'TPHI' LO 'TPLO'$

        MEASURE (FREQ 'FREQ' HZ), AC-SIGNAL, FREQ MAX 50000 HZ,
        VOLTAGE MAX 'VMAX' V, CNX HI 'TPHI'$

        MEASURE (VOLTAGE 'VAC' V), AC-SIGNAL, FREQ 'FREQ'  HZ,
        VOLTAGE MAX 'VMAX' V, CNX HI 'TPHI' LO 'TPLO'$

        RECORD 'FREQ',"MEASURED FREQUENCY IS = ###.#### HZ"$
```

```
   RECORD 'VAC',"MEASURED VOLTAGE IS = ###.######## VAC"$
   COMPARE 'STEP', GT 'MAXSTP'$
   GOTO STEP 40 IF GO$
   'STEP' = 'STEP' + 1$
   GOTO STEP 30$

 40 DISPLAY, "
          *****************************************
          *  PRESS <YES> TO SELECT NEW P.I.U. PINS  *
          *  PRESS  <NO> TO TERMINATE THIS PROGRAM  *
          *****************************************"$
   WAIT-FOR MANUAL-DATA-GO-NOGO$
   GOTO STEP 20 IF GO$
   PRINT, "!P"$
E  999 TERMINATE$
```

```
C      BEGIN PROGRAM TO TEST AC-CALIBRATION OF EQUATE$
C      IN THE HIGH-FREQUENCY REGION (60 KHZ TO 10MHZ)$
C      BY T.LEEDY N.B.S. 4/21/81$

       DECLARE DECIMAL, 'VAC', 'VMAX'$
       DECLARE DECIMAL, 'STEP', MAXSTP', 'TPHI', 'TPLO'$
       DEFINE 'LINE', RECORD " "$


E    5 'LINE'$
       SELECT PIU$

       DISPLAY, "*********************************************
                 * THIS PROGRAM WILL MEASURE THE A.C. VOLTAGE *
                 * AT THE P.I.U. INPUTS (TPHI) AND (TPLO)     *
                 * (ASSURE THAT THE SWITCH ON THE ADAPTER IS  *
                 *       SET TO THE  HF   POSITION)
                 *      PRESS (PROCEED) TO CONTINUE           *
                 *********************************************"$
       WAIT-FOR MANUAL-INTERVENTION$


    10 'LINE'$
       DISPLAY, "ENTER NUMBER OF STEPS DESIRED"$
       DISPLAY, "MAXIMUM NUMBER OF STEPS IS 56"$
       INPUT 'MAXSTP'$
       'LINE'$
       RECORD, "***** PARAMETERS OF TEST *****"$
       'LINE'$
       RECORD,'MAXSTP', "NUMBER OF STEPS =#.STEPS"$

    20 'STEP'= 1$
       DISPLAY, "ENTER P.I.U. PINS UNDER TEST -- TPHI AND TPLO"$
       INPUT 'TPHI'$
       INPUT 'TPLO'$
       RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
       RECORD, 'TPLO', "AND PIN TPLO IS NUMBER  = #."$
    30 CONNECT EARTH, CNX TP 128$
       CONNECT EARTH, CNX TP 'TPLO'$
       APPLY DC-SIGNAL DC2A, VOLTAGE 5V, CNX HI 127 LO 128$
       DELAY 0.01 SEC$
       REMOVE DC2A$

       DELAY 3 SEC$

       MEASURE (FREQ 'FREQ' HZ), AC-SIGNAL, FREQ MAX 10. MHZ,
       VOLTAGE MAX 3.5 V, CNX HI 'TPHI'$

       COMPARE 'FREQ', GT 50000$
       GOTO STEP 34 IF GO$
       GOTO STEP 36 IF NOGO$

       MEASURE (VOLTAGE-TRMS 'VAC' V), AC-SIGNAL, VOLTAGE-TRMS MAX 3.5 V,
       FREQ MAX 'FREQ' HZ, TEST-EQUIP-IMP 50 OHM,
```

```
    CNX HI 'TPHI'$

    MEASURE (FREQ 'FREQ' HZ), AC-SIGNAL, FREQ MAX 50000 HZ,
    GOTO STEP 38$

 36 MEASURE (VOLTAGE 'VAC' V), AC-SIGNAL, FREQ 'FREQ'  HZ,
    VOLTAGE MAX 6.5 V, BUFFERED, CNX HI 'TPHI'$


    RECORD 'FREQ',"MEASURED FREQUENCY IS = ###.#### HZ"$

    RECORD 'VAC',"MEASURED VOLTAGE IS = ###.######## VAC"$
    COMPARE 'STEP', GT 'MAXSTP'$
    GOTO STEP 40 IF GO$
    'STEP' = 'STEP' + 1$
    GOTO STEP 30$

 40 DISPLAY, "
               ******************************************
               *  PRESS <YES> TO SELECT NEW P.I.U. PINS  *
               *  PRESS  <NO> TO TERMINATE THIS PROGRAM  *
               ******************************************"$
    WAIT-FOR MANUAL-DATA-GO-NOGO$
    GOTO STEP 20 IF GO$
    PRINT, "!P"$
E  999 TERMINATE$
```

APPENDIX B

Listing of the ATLAS program DCV, ACVL, and ACVH run on the Navy EQUATE System

```
   DECLARE DECIMAL, 'VDC', 'VMAX'$
   DECLARE DECIMAL, 'STEP', 'MAXSTP', 'TPHI', 'TPLO'$
   DEFINE 'LINE', RECORD " "$
E 5 'LINE'$
   DISPLAY, " THIS PROGRAM WILL MEASURE THE D.C. VOLTAGE
            AT THE P.I.U INPUTS  <TPHI> AND <TPLO>.
              PRESS <PROCEED> TO CONTINUE ...           "$
   WAIT-FOR MANUAL-INTERVENTION$
 10 'LINE'$
   DISPLAY, "ENTER NUMBER OF STEPS DESIRED"$
   DISPLAY, "MAXIMUM NUMBER OF STEPS IS 50"$
   INPUT 'MAXSTP'$
   'LINE'$
   RECORD, "*** PARAMETERS OF TEST  (NAC)   ***"$
   'LINE'$
   RECORD, 'MAXSTP', "NUMBER OF STEPS =#.STEPS"$
 20 'STEP' = 1 $
   DISPLAY, "ENTER P.I.U. PINS UNDER TEST -- TPHI AND TPLO"$
   INPUT 'TPHI'$
   INPUT 'TPLO'$
   RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
   RECORD, 'TPLO', "TEST AT PIN NUMBER TPLO = #."$
   CONNECT PIU, LOAD-IMP 0 OHM, CNX UTP 82$
   CONNECT PIU,DC2-POS,CNX UTP 81$
   CONNECT PIU,DC2-NEG,CNX UTP 82$
   SETUP DC-SIGNAL DC2,VOLTAGE 0 V$
   CLOSE DC-SIGNAL DC2 $
   DELAY 0.5 SEC$
 30 SETUP DC-SIGNAL DC2,VOLTAGE 5 V$
   DELAY 1 SEC$
   SETUP DC-SIGNAL DC2,VOLTAGE 0 V$
   DELAY 3 SEC$
   MEASURE (VOLTAGE 'VMAX' V), DC-SIGNAL,
   DELAY 0.3 SEC,CNX HI 'TPHI' LO 'TPLO'$
   MEASURE (VOLTAGE 'VDC' V), DC-SIGNAL, VOLTAGE MAX 'VMAX' V,
   DELAY 0.3 SEC,CNX HI 'TPHI' LO 'TPLO'$
   RECORD 'VDC', "MEASURED VOLTAGE IS = ###.######## VDC"$
   COMPARE 'STEP', GT 'MAXSTP'$
   GOTO STEP 40 IF GO$
   'STEP' = 'STEP' + 1$
   GOTO STEP 30$
 40 DISPLAY, "   PRESS <YES> TO SELECT NEW P.I.U. PINS
              PRESS <NO>  TO TERMINATE THIS PROGRAM.   "$
   WAIT-FOR MANUAL-DATA-GO-NOGO$
   GOTO STEP 20 IF GO$
   PRINT "!P"$
   TERMINATE$
```

```
C  BEGIN PROGRAM TO TEST AC-CALIBRATION OF EQUATE$
C  IN THE LOW FREQUENCY REGION (100 HZ TO 50 KHZ)$
C  RE-KEYED AT NAC 7/14/81  T. LEEDY$
   DECLARE DECIMAL, 'VAC', 'VMAX', 'FREQ'$
    DECLARE DECIMAL, 'STEP', 'MAXSTP', 'TPHI', 'TPLO'$
   DEFINE 'LINE', RECORD " "$
5  'LINE'$
   DISPLAY, "  THIS PROGRAM WILL MEASURE THE A.C. VOLTAGE
             AT THE P. I. U. INPUTS (TPHI) AND (TPLO).
               PRESS (PROCEED) TO CONTINUE ...           "$
   WAIT-FOR MANUAL-INTERVENTION$
E 10 'LINE'$
   DISPLAY, "ENTER NUMBER OF STEPS DESIRED"$
   DISPLAY, "MAXIMUM NUMBER OF STEPS IS 64"$
   INPUT 'MAXSTP'$
   'LINE'$
   RECORD, "*** PARAMETERS OF TEST *** (NAC)"$
   'LINE'$
   RECORD, 'MAXSTP', "NUMBER OF STEPS = #. STEPS"$
20 'STEP'=1$
   DISPLAY, "ENTER P.I.U. PINS UNDER TEST -- TPHI AND TPLO"$
   INPUT 'TPHI'$
   INPUT 'TPLO'$
   RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
   RECORD, 'TPLO', "AND PIN TPLO IS NUMBER  =#."$
   CONNECT PIU, LOAD-IMP 0 OHM, CNX UTP 82$
   CONNECT PIU,DC2-POS,CNX UTP 81$
   CONNECT PIU,DC2-NEG,CNX UTP 82$
   SETUP DC-SIGNAL DC2,VOLTAGE 0V$
   CLOSE DC-SIGNAL DC2$
   DELAY 0.5 SEC$
30 SETUP DC-SIGNAL DC2,VOLTAGE 5V$
   DELAY 1 SEC$
   SETUP DC-SIGNAL DC2,VOLTAGE 0V$
   DELAY 2.5 SEC$
   MEASURE (VOLTAGE 'VMAX' V), AC-SIGNAL, VOLTAGE MAX 140 V, FREQ 100 HZ,
   DELAY 0.5 SEC,CNX HI 'TPHI' LO 'TPLO'$
   COMPARE 'VMAX',LT 60$ GOTO STEP 35 IF GO$
   RECORD "NO FREQ MEASUREMENT FOR > 60 VAC"$
   'FREQ' = 100 $ GOTO STEP 37$
35 CONNECT PIU,LOAD-IMP 0 OHM,CNX UTP 'TPLO'$
   MEASURE (FREQ 'FREQ' HZ), AC-SIGNAL, FREQ MAX 49.90 KHZ,
   VOLTAGE MAX 'VMAX' V, DELAY 0.5 SEC,CNX HI 'TPHI'$
   DISCONNECT PIU,LOAD-IMP 0 OHM,CNX UTP 'TPLO'$
37 MEASURE (VOLTAGE 'VAC' V), AC-SIGNAL, FREQ 'FREQ' HZ,
   DELAY 0.5 SEC,VOLTAGE MAX 'VMAX' V, CNX HI 'TPHI' LO 'TPLO'$
   RECORD 'FREQ', "MEASURED FREQUENCY IS ######.## HZ",'STEP'," STEP = ##"$
   RECORD 'VAC', "MEASURED VOLTAGE IS ###.######## VAC"$
   COMPARE 'STEP', GT 'MAXSTP'$
   GOTO STEP 40 IF GO$
   'STEP' = 'STEP' + 1$
   GOTO STEP 30$
40 DISPLAY, "PRESS (YES) TO SELECT NEW P.I.U. PINS
             PRESS (NO)  TO TERMINATE THIS PROGRAM  "$
```

```
WAIT-FOR MANUAL-DATA-GO-NOGO$
GOTO STEP 20 IF GO$
PRINT "!P"$
TERMINATE$
```

```
C   BEGIN PROGRAM TO TEST AC-CALIBRATION OF EQUATE$
C   IN THE HIGH FREQUENCY REGION (50 KHZ TO 10MHZ)$
C   RE-KEYED AT NAC 7/14/81  T. LEEDY$
    DECLARE DECIMAL, 'VAC', 'VMAX', 'FREQ'$
     DECLARE DECIMAL, 'STEP', 'MAXSTP', 'TPHI', 'TPLO'$
    DEFINE 'LINE', RECORD " "$
5   'LINE'$
    DISPLAY, "THIS PROGRAM IS TO MEASURE THE A.C. VOLTAGE
               AT THE P.I.U. INPUT (TPHI) AND RESPECTIVE
                 SHIELD IN THE RANGE OF 50 KHZ TO 10 MHZ.

                 3 VAC IS THE MAX.VOLTAGE  PERMITTED
                 PRESS (PROCEED) TO CONTINUE
                                                ......... "$
    WAIT-FOR MANUAL-INTERVENTION$
10  'LINE'$   DISPLAY, "ENTER THE NUMBER OF STEPS DESIRED"$
    DISPLAY, "THE MAXIMUM NUMBER OF STEPS IS 53"$
    INPUT 'MAXSTP'$
    'LINE'$
    RECORD, "*** PARAMETERS OF THE TEST *** (NAC)"$
    'LINE'$
    RECORD, 'MAXSTP', "NUMBER OF STEPS =#. STEPS"$
20  'STEP' = 1$
    DISPLAY, "ENTER P.I.U. PIN UNDER TEST -- TPHI "$
    INPUT 'TPHI'$
    RECORD, 'TPHI', "TEST AT PIN NUMBER TPHI = #."$
    CONNECT PIU, LOAD-IMP 0 OHM, CNX UTP 82$
    CONNECT PIU,DC2-POS,CNX UTP 81$
    CONNECT PIU,DC2-NEG,CNX UTP 82$
    SETUP DC-SIGNAL DC2,VOLTAGE 0$
    CLOSE DC-SIGNAL DC2$
30  SETUP DC-SIGNAL DC2,VOLTAGE 5V$
    DELAY 0.2 SEC$
    SETUP DC-SIGNAL DC2,VOLTAGE 0V$
    DELAY 2.5 SEC$
    MEASURE (VOLTAGE-TRMS 'VMAX' V),AC-SIGNAL,VOLTAGE-TRMS MAX 3.0 V,
     FREQ MAX 5 MHZ,TEST-EQUIP-IMP 50 OHM,BUFFERED,CNX HI 'TPHI'$
    MEASURE (FREQ 'FREQ' MHZ), AC-SIGNAL, FREQ MAX 9.9 MHZ,
    VOLTAGE MAX 3.0 V, CNX HI 'TPHI'$
    COMPARE 'FREQ', GT 0.05$
    GOTO STEP 34 IF GO$
    RECORD, "FREQUENCY LESS THAN 50 KHZ , NO MEASUREMENT MADE"$
    GOTO STEP 30 IF NOGO$
34  COMPARE 'FREQ',GT 1 $ GOTO STEP 35 IF GO$
    'FREQ' =5$
35  MEASURE (VOLTAGE-TRMS 'VAC' V), AC-SIGNAL, VOLTAGE-TRMS MAX 'VMAX' V,
    FREQ MAX 'FREQ' MHZ, TEST-EQUIP-IMP 50 OHM, BUFFERED,
    CNX HI 'TPHI'$

38  RECORD 'FREQ', "MEASURED FREQ. = ###.## HZ",'STEP'," STEP = ##"$
39  RECORD 'VAC', "MEASURED VOLTAGE IS = ###.#### VAC"$
    COMPARE 'STEP' , GT 'MAXSTP'$
    GOTO STEP 40 IF GO$
    'STEP' = 'STEP' +1 $
```

```
   GOTO STEP 30$

40 DISPLAY "   PRESS <YES> TO SELECT NEW P.I.U. PINS
               PRESS <NO>  TO TERMINATE THIS PROGRAM    ... "$
   WAIT-FOR MANUAL-DATA-GO-NOGO$   GOTO STEP 20 IF GO$
   REMOVE ALL$
   PRINT "!P"$
99 TERMINATE$
```

APPENDIX C

Listing of the ATLAS program to acquire PIU pulse measurement data on the Navy EQUATE System

```
                BEGIN PROGRAM TO MEASURE VP-MAX AND VP-MIN$
  C             TRANSITION DURATION AND PULSE DURATION$
  C             BY W. L. GANS$

                DECLARE DECIMAL,'DC','P','VMIN','VMAX','VMINM','VMAXM',
                  'MHITP','MLOTP','THRESHOLD','NINE','TEN','PDPN','TR',
                  'VMINB','VMAXB','THRESHB','NINEB','TENB'$
                DEFINE 'LINE',RECORD," "$
 E  110         DISPLAY,"
                        ***********************************************
                        * THIS PROGRAM WILL MEASURE VOLTAGE-P-MAX,    *
                        * VOLTAGE-P-MIN, PULSE TRANSITION DURATION,   *
                        * AND PULSE DURATION THRU THE PIU ABOVE       *
                        * 50 KHZ AND INTO THE 50 OHM LOAD.            *
                        * PRESS PROCEED TO CONTINUE OR PRESS          *
                        * HALT TO TERMINATE.                          *
                        ***********************************************"$


                WAIT-FOR MANUAL-INTERVENTION$

    120         REMOVE ALL$

                DISPLAY,"ENTER DUTY-CYCLE"$
                INPUT 'DC'$
                RECORD 'DC',"DUTY-CYCLE = ##.# %"$

                DISPLAY,"ENTER VOLTAGE-MAX"$
                INPUT 'VMAX'$
                RECORD 'VMAX',"VOLTAGE-MAX = #.## VDC"$

                DISPLAY,"ENTER VOLTAGE-MIN"$
                INPUT 'VMIN'$
                RECORD 'VMIN',"VOLTAGE-MIN = #.## VDC"$

                DISPLAY,"ENTER PERIOD IN USEC"$
                INPUT 'P'$
                RECORD 'P',"PERIOD = #.## USEC"$

    130         DISPLAY,"ENTER MEAS. HI TEST POINT"$
                INPUT 'MHITP'$
                RECORD 'MHITP',"MEAS. HI TEST POINT = ####"$


                'LINE'$

                MEASURE(VOLTAGE-P-MAX 'VMAXM' V),PULSED-DC,
                VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
                TEST-EQUIP-IMP 50 OHM,CNX HI 'MHITP'$

                'LINE'$

                RECORD 'VMAXM',"VOLTAGE-P-MAX (UNBUFF) = ####.##### V"$

                'LINE'$

                CONNECT PIU,LOAD-IMP 50 OHM,CNX UTP 'MHITP'$
                DELAY 0.5 SEC$
```

```
MEASURE(VOLTAGE-P-MAX 'VMAXB' V),PULSED-DC,
VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
BUFFERED,CNX HI 'MHITP'$
RECORD 'VMAXB',"VOLTAGE-P-MAX (BUFF) = ####.##### V"$
DISCONNECT PIU,LOAD-IMP 50 OHM,CNX UTP 'MHITP'$
'LINE'$
MEASURE(VOLTAGE-P-MIN 'VMINM' V),PULSED-DC,
VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
TEST-EQUIP-IMP 50 OHM,CNX HI 'MHITP'$
'LINE'$
RECORD 'VMINM',"VOLTAGE-P-MIN (UNBUFF) = ####.##### V"$
'LINE'$
CONNECT PIU,LOAD-IMP 50 OHM,CNX UTP 'MHITP'$
DELAY 0.5 SEC$
MEASURE(VOLTAGE-P-MIN 'VMINB' V),PULSED-DC,
VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
BUFFERED,CNX HI 'MHITP'$
'LINE'$
DISCONNECT PIU,LOAD-IMP 50 OHM,CNX UTP 'MHITP'$
RECORD 'VMINB',"VOLTAGE-P-MIN (BUFF) = ####.##### V"$
'LINE'$
'THRESHOLD'= ('VMINM' + 'VMAXM')/2$
RECORD 'THRESHOLD',"THRESHOLD (UNBUFF) = ####.##### V"$
'LINE'$
'THRESHB'= ('VMINB' + 'VMAXB')/2$
RECORD 'THRESHB',"THRESHOLD (BUFF) = ####.##### V"$
'LINE'$
'NINE'='VMINM' + 0.9*ABS('VMAXM' - 'VMINM')$
RECORD 'NINE',"NINETY (UNBUFF) = ####.##### V"$
'LINE'$
'NINEB'='VMINB' + 0.9*ABS('VMAXB' - 'VMINB')$
RECORD 'NINEB',"NINETY (BUFF) = ####.##### V"$
'LINE'$
'TEN'='VMINM' + 0.1*ABS('VMAXM' - 'VMINM')$
RECORD 'TEN',"TEN (UNBUFF) = ####.##### V"$
'LINE'$
'TENB'='VMINB' + 0.1*ABS('VMAXB' - 'VMINB')$
RECORD 'TENB',"TEN (BUFF) = ####.##### V"$
```

```
C               BEGIN TIME-INTERVAL MEASUREMENT PROGRAM$


                MEASURE (TIME 'TR' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'TEN' V, POS-SLOPE, TEST-EQUIP-IMP 50 OHM,
                CNX HI 'MHITP', STOP, THRESHOLD 'NINE' V, POS-SLOPE$

                'LINE'$

                RECORD'TR', "FIRST TRANSITION DURATION (UNBUFF) = ####.##### NSEC"$

                'LINE'$

                CONNECT PIU, LOAD-IMP 50 OHM, CNX UTP 'MHITP'$
                DELAY 0.5 SEC$
                MEASURE (TIME 'TR' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, BUFFERED, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'TENB' V, POS-SLOPE,
                CNX HI 'MHITP', STOP, THRESHOLD 'NINEB' V, POS-SLOPE$

                'LINE'$
                DISCONNECT PIU, LOAD-IMP 50 OHM, CNX UTP 'MHITP'$
                RECORD 'TR', "FIRST TRANSITION DURATION (BUFF) = ####.##### NSEC"$


                'LINE'$

                MEASURE (TIME 'PDPN' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'THRESHOLD' V, POS-SLOPE, TEST-EQUIP-IMP 50 OHM,
                CNX HI 'MHITP', STOP, THRESHOLD 'THRESHOLD' V, NEG-SLOPE$

                'LINE'$

                RECORD'PDPN', "PULSE DURATION (UNBUFF) = ####.##### NSEC"$

                'LINE'$

                CONNECT PIU, LOAD-IMP 50 OHM, CNX UTP 'MHITP'$
                DELAY 0.5 SEC$
                MEASURE (TIME 'PDPN' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, BUFFERED, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'THRESHB' V, POS-SLOPE, CNX HI 'MHITP',
                STOP, THRESHOLD 'THRESHB' V, NEG-SLOPE$

                'LINE'$
                DISCONNECT PIU, LOAD-IMP 50 OHM, CNX UTP 'MHITP'$
                RECORD 'PDPN', "PULSE DURATION (BUFF) = ####.##### NSEC"$

                PRINT "\"$

                DISPLAY"
                        PRESS YES TO RERUN PROGRAM
                        PRESS NO TO TERMINATE"$

                WAIT-FOR MANUAL-DATA-GO-NOGO$
                GOTO STEP 110 IF GO$
                GOTO STEP 99999 IF NOGO$
```

```
175:     99999     REMOVE ALL$
176:               TERMINATE$
```

APPENDIX D

A typical pulse measurement printout from the PIU tests

DUTY-CYCLE =   1.0 %
VOLTAGE-MAX = 2.50 VDC
VOLTAGE-MIN = 0.00 VDC
PERIOD = 10.00 USEC
MEAS. HI TEST POINT =   1

VOLTAGE-P-MAX (UNBUFF) =   1.71565 V

VOLTAGE-P-MAX (BUFF) =   2.85253 V

VOLTAGE-P-MIN (UNBUFF) =   0.00213 V

VOLTAGE-P-MIN (BUFF) =   0.01159 V

THRESHOLD (UNBUFF) =   0.85889 V

THRESHOLD (BUFF) =   1.43206 V

NINETY (UNBUFF) =   1.54429 V

NINETY (BUFF) =   2.56843 V

TEN (UNBUFF) =   0.17348 V

TEN (BUFF) =   0.29569 V

FIRST TRANSITION DURATION (UNBUFF) = 9740.00000 NSEC

FIRST TRANSITION DURATION (BUFF) = 9740.00000 NSEC

PULSE DURATION (UNBUFF) = 112.00000 NSEC

PULSE DURATION (BUFF) =   98.89999 NSEC

APPENDIX E

Listing of the ATLAS program to acquire DIU pulse measurement data on the Navy EQUATE System

```
C              BEGIN PROGRAM TO MEASURE VP-MAX AND VP-MIN$
C              TRANSITION DURATION AND PULSE DURATION$
C              BY W. L. GANS$

               DECLARE DECIMAL,'DC','P','VMIN','VMAX','VMINM','VMAXM',
                 'MHITP','MLOTP','THRESHOLD','NINE','TEN','PDPN','TR'$

               DEFINE 'LINE',RECORD," "$
E 110          DISPLAY,"
                           ********************************************
                           * THIS PROGRAM WILL MEASURE VOLTAGE-P-MAX, *
                           * VOLTAGE-P-MIN, PULSE TRANSITION DURATION,*
                           * AND PULSE DURATION THRU THE DIU ABOVE    *
                           * 50 KHZ AND INTO THE 50 OHM LOAD.         *
                           * PRESS PROCEED TO CONTINUE OR PRESS       *
                           * HALT TO TERMINATE.                       *
                           ********************************************"$


               WAIT-FOR MANUAL-INTERVENTION$

  120          REMOVE ALL$

               DISPLAY,"ENTER DUTY-CYCLE"$
               INPUT 'DC'$
               RECORD 'DC',"DUTY-CYCLE = ##.# %"$

               DISPLAY,"ENTER VOLTAGE-MAX"$
               INPUT 'VMAX'$
               RECORD 'VMAX',"VOLTAGE-MAX = #.## VDC"$

               DISPLAY,"ENTER VOLTAGE-MIN"$
               INPUT 'VMIN'$
               RECORD 'VMIN',"VOLTAGE-MIN = #.## VDC"$

               DISPLAY,"ENTER PERIOD IN USEC"$
               INPUT 'P'$
               RECORD 'P',"PERIOD = #.## USEC"$


               'LINE'$

               MEASURE(VOLTAGE-P-MAX 'VMAXM' V),PULSED-DC,
               VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
               TEST-EQUIP-IMP 50 OHM,CNX BNC 1$

               'LINE'$

               RECORD 'VMAXM',"VOLTAGE-P-MAX = ####.#####"$

               'LINE'$

               MEASURE(VOLTAGE-P-MIN 'VMINM' V),PULSED-DC,
               VOLTAGE MAX 'VMAX' V,PERIOD 'P' USEC,DUTY-CYCLE 'DC' PC,
               TEST-EQUIP-IMP 50 OHM,CNX BNC 1$

               'LINE'$
```

```
                RECORD 'VMINM', "VOLTAGE-P-MIN = ####.##### V"$
                'LINE'$
                'THRESHOLD'= ('VMINM' + 'VMAXM')/2$
                RECORD 'THRESHOLD', "THRESHOLD = ####.##### V"$
                'LINE'$
                'NINE'='VMINM'+0.9*ABS('VMAXM'-'VMINM')$
                RECORD 'NINE', "NINETY = ####.##### V"$
                'LINE'$
                'TEN'='VMINM'+0.1*ABS('VMAXM'-'VMINM')$
                RECORD 'TEN', "TEN = ####.##### V"$
                'LINE'$


C               BEGIN TIME-INTERVAL MEASUREMENT PROGRAM$



                MEASURE(TIME 'TR' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'TEN' V, POS-SLOPE, TEST-EQUIP-IMP 50 OHM,
                CNX BNC 1, STOP, THRESHOLD 'NINE' V, POS-SLOPE$
                'LINE'$
                RECORD'TR', "FIRST TRANSITION DURATION = ####.##### NSEC"$
                'LINE'$


                MEASURE(TIME 'PDPN' NSEC), TIME-INTERVAL, SINGLE-CHANNEL,
                MAX-TIME 1 SEC, START, VOLTAGE MAX 'VMAX' V,
                THRESHOLD 'THRESHOLD' V, POS-SLOPE, TEST-EQUIP-IMP 50 OHM,
                CNX BNC 1, STOP, THRESHOLD 'THRESHOLD' V, NEG-SLOPE$
                'LINE'$
                RECORD'PDPN', "PULSE DURATION = ####.##### NSEC"$
                'LINE'$

                DISPLAY"
                        PRESS YES TO RERUN PROGRAM
                        PRESS NO TO TERMINATE"$

                WAIT-FOR MANUAL-DATA-GO-NOGO$
                GOTO STEP 110 IF GO$
                GOTO STEP 99999 IF NOGO$
     99999      REMOVE ALL$
                TERMINATE$
```

APPENDIX F

A typical pulse measurement printout from the DIU tests

DUTY-CYCLE =   0.5 %
VOLTAGE-MAX = 2.50 VDC
VOLTAGE-MIN = 0.00 VDC
PERIOD = 10.00 USEC

VOLTAGE-P-MAX =   2.35426

VOLTAGE-P-MIN =   0.00274 V

THRESHOLD =   1.17850 V

NINETY =   2.11911 V

TEN =   0.23789 V

FIRST TRANSITION DURATION = 10004.00000 NSEC

PULSE DURATION =   49.99999 NSEC

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This work describes an experimental approach to verify the performance of selected third generation automatic test systems. The approach consisted of careful laboratory characterization of two types of signal sources. One was a dc and low frequency ac voltage source covering the range of approximately 100 mV to 200 V dc, and 300 mV to 140 V ac rms over a frequency range of 100 Hz to 10 MHz. The second source was a precision time synthesizer used to generate pulses of known durations from 50 to 1000 ns. Both of these sources were used to verify the ability of two automatic test systems to measure ac and dc voltages and time intervals. The methods used to characterize these sources and the measurement results of applying the sources to the two automatic test systems are discussed in detail. Recommendations for future efforts to improve the measurement capabilities and traceability of automatic test systems are also presented.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

ATE; automatic test systems; calibration; characterization; dynamic transport standard; evaluation; field calibration; performance test; third generation system

13. AVAILABILITY

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