NASA Technical Memorandum 102500

High Power, High Frequency Component Test Facility

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February 1990

NASA

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SUMMARY

NASA Lewis Research Center has available a high frequency, high power laboratory facility for testing various components of aerospace and/or terrestrial power systems. This paper describes this facility, detailing all of its capabilities and potential applications.

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INTRODUCTION

The High Power High Frequency Component Test Facility was developed for the testing of prototype as well as commercially available high frequency, high power components. Power systems for various space applications (Space Station, Lunar Base, Mars Rover) favor high frequency distribution systems, due to the improved safety and weight factors offered by those systems. Other favorable characteristics include low EMI, minimal wiring, ease of system parameter sensing and control for a single phase system. A facility to test and evaluate components for such systems is necessary for the development of high frequency, high power technologies. A solid technology base is vital to the development of sophisticated power systems of the future. Components of such a system include: transmission lines, connectors, transformers, capacitors, switching devices, and rotary power transfer devices.

FACILITY FEATURES

The component test facility is equipped with several high frequency sources ranging from 1500 W to 100 kW. Instrumentation for accurate measurements is essential. Voltmeters, current monitors and transformers, power meters, oscilloscopes and a spectrum analyzer are available. The vacuum system includes a residual gas analyzer and a neon gas system for use as a trace gas for outgassing measurements. A screen room (R.F.I. Shielded Enclosure) for EMI testing of components is also available. A high temperature environment is available for the evaluation of high temperature insulations. This facility is also equipped with a high frequency distribution network. A detailed account of each aspect of the component test facility follows.

POWER SOURCES

The high frequency, high power component test facility has several power sources. These sources range from 1500 W to 100 kW. The frequency range varies from source to source and overall, is 8 to 250 kHz.

The ENI model 1140LA is an all solid-state power amplifier. It has a frequency range of 9 to 250 kHz with maximum power output of 1500 W into any load from 40 to 60 Ω. However, it will operate into both an open and shorted load. The amplifier will operate with any function generator or oscillator up to a 3 V peak to peak signal.

The 1140LA is equipped with various protection circuitry which will automatically shut-off the amplifier should the power transistors overheat due to a load mismatch or failure in the cooling system. The amplifier can be reset once the problem is corrected. This source is equipped with a power meter with an accuracy of better than 3 percent of full-scale (2000 W). Both forward power (power output of the amplifier) and load power (power absorbed by the load) are measured. Four hundred watts of reflected power (the difference between the forward and load power) is tolerated by the amplifier's circuitry. Reflected power greater than 400 W results in automatic shutdown of the amplifier. The maximum voltage into a 50 Ω load is 270 V. Various power transformers are available to obtain the desired voltage level for each specific application. If the transformers do not provide the appropriate voltage level, case specific matching networks are then used.

Power requirements: 115 V ac, 50 to 60 Hz, 35 A RMS maximum
Size: 8-3/4 in. by 17 in. by 20-1/4 in.
Weight: 50 lb

The ENI model EGR - 3200B is a 3 kW, all solid state generator. The generator can deliver up to 3000 W over a frequency span of 8 to 110 kHz. For maximum power, the load must be between 40 to 55 Ω. This unit can also operate into a shorted or open load. The 3200B is a class B type, or nonlinear amplifier. However, with load specific matching networks, maximum power can be delivered, still maintaining a sinusoidal output with minimum distortion.

The 3200B is equipped with the same type of protection circuitry as the 1140LA model. The unit also has a power meter to monitor the forward and load power. Up to 700 W of reflected power can be tolerated by the generator. The maximum voltage at full power (50 Ω load) is 387 V. Various power transformers as well as case specific matching networks can be used to obtain the desired voltage level.

Power requirements: 208 V, single phase, 50 to 60 Hz. 40 A maximum
Size: 26.5 by 17 by 22.5 in.
Weight: 135 lb

The ENI model EGR-9600B is an all solid state generator that can deliver up to 9000 W over a frequency range of 8 to 111 kHz. Maximum power transfer is possible into loads ranging from 40 to 56 Ω. The generator includes a class B, nonlinear amplifier. However, with load specific matching networks, the generator can provide a sinusoidal output with minimum distortion near maximum power output.

The 9600B is equipped with overload protection similar to the previous models. It is equipped with a true average power meter as well. This generator can tolerate up to 1500 W of reflected power.

Power requirements: 208 V, 3-phase, 50 to 60 Hz, 80 A maximum
Dimensions: 44 by 29 by 30 in.
Weight: 350 lb

The largest capacity source offered by the facility is an Industrial Electric Heating (IEH) model, 100 kW, 20 kHz Inverter (fig. 1). A simplified schematic of the firing circuitry is shown in figure 2. The basic theory of operation follows.

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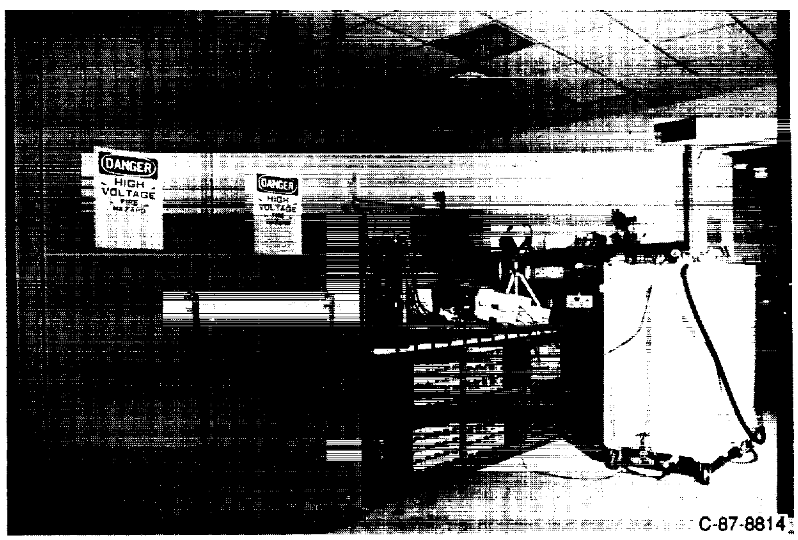
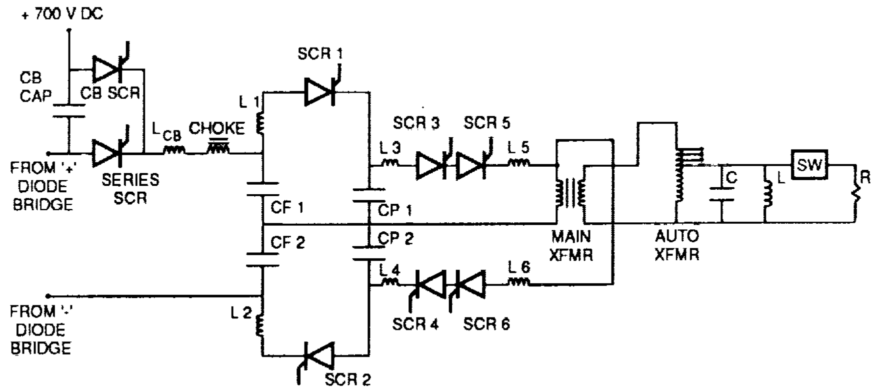
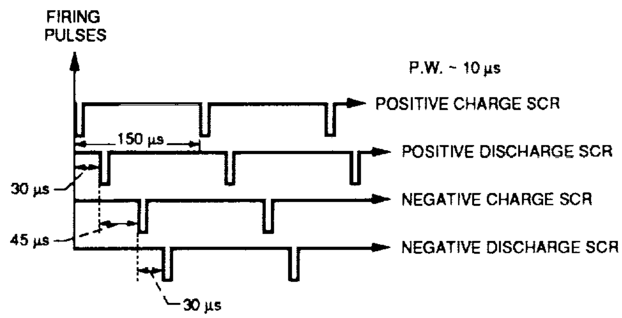


Figure 1. - 20-KHz power sources and instrumentation for power measurements (IEH 100-kW source).

The three phase, 480 V, 60 Hz input is rectified and this energy is stored in capacitor banks CF1 and CF2. CF1 is charged to +300 V dc, CF2 is charged to -300 V dc. SCR1 is the positive charge SCR, SCR2 is the negative. SCR1 fires, charging CP1 to +900 V dc. SCR2 fires, charging CP2 to -900 V dc. SCR's 3 and 5, the positive discharge SCRs, fire dumping one positive pulse of energy into the main transformer. SCR's 4 and 6, the negative discharge SCRs, fire dumping one negative pulse of energy into the main transformer. The firing order of the SCRs is also depicted in figure 2. When the unit operates at its maximum firing rate of 6.7 kHz, the tank circuit, which is tuned to 20 kHz, receives one positive pulse and then 75 μsec later, or 1-1/2 cycles, a negative pulse. Consequently, the output at the tank is a 20 kHz sinusoid. By adjusting the tank circuit, its Q, the main transformer, CP1, CP2 and/or the auto transformer, the desired voltage output can be obtained at the maximum firing rate, resulting in the best possible waveform.



(a) Simplified inverter design.



(b) Firing order.

Figure 2. - Firing circuitry of IEH source.

INSTRUMENTATION

This facility is for the testing and evaluation of various high frequency, high power components. To make valid evaluations of such components, accurate measurements of voltage, current, phase, and power are essential. Instrumentation must have a high degree of accuracy at 20 kHz (and its higher order harmonics) and must also have the capability to make floating measurements, when necessary. Instrumentation includes: Fluke True RMS voltmeter and DMM, Pearson current monitors and current transformers, Yokagawa power meter, Tektronix, Nicolet and Hitachi oscilloscopes, and Corona Test Equipment. Detailed information follows.

Voltage Measurements

Two different model Fluke meters have been used to measure voltage, 8920A and the 8060A. The 8920A is a true RMS voltmeter, line operated. The RMS measurement is made with a thermal RMS convertor which will accept sine, complex, pulse and random waveforms. The allowable crest factor at full scale is 7. Both ac and ac + dc true RMS measurements are possible, as well as decibel measurements. The maximum input is 700 V ac RMS or 1000 V peak, not to exceed 1×10^8 V × Hz. The meter has an isolated BNC input with a 10 MΩ input resistance shunted by <30 pF capacitor.

For decibel measurements, all voltage inputs are referenced to a selected level. A 0 dB reference level can be set by the user. All measurements are then made with respect to the selected level. The following tables contain the frequency and accuracy specifications for voltage measurements.

TABLE I. - FREQUENCY RANGE FOR FLUKE 8920A

Voltage range	Maximum frequency limit, MHz
2 mV	2
20 mV - 20 V	20
200 V - 700 V	1

TABLE II. - ACCURACY FOR FLUKE 8920A

Voltage range	Accuracy
200 mV - 700 V	Better than 0.7 percent of reading up to 1 MHz
2 mV - 200 mV	Better than 3 percent of reading up to 1 MHz

(a) Alternating current

20 mV - 700 V	Better than 3 percent of reading up to 1 MHz
2 mV	Better than 3 percent of reading at 2 mV and 30 percent of reading at 180 μV, up to 1 MHz

(b) Alternating plus direct current

In certain instances, it is necessary to be able to make floating measurements. In these instances, a Fluke model 8060A is used. The 8060A is a handheld, battery operated 4-1/2 digit multimeter. This multimeter has many features including: measurement of voltage, both ac and dc, frequency, current, decibel, resistance, conductance; a diode test, continuity check and a relative function to be used with all of the above, except continuity.

The 8060A is capable of true RMS voltage measurements up to 100 kHz. Accuracy at 20 kHz is better than 1 percent from 10 mV to 200 V. Although no data is provided for voltages exceeding 200 V, a comparison of the 8060A with the 8920A true RMS voltmeter, indicates the former to be a reliable instrument at these higher voltages. This multimeter has an input resistance of 10 MΩ shunted by <100 pF. It has a crest factor range of 1:1 to 3:1 and can withstand an overvoltage of 750 V ac or 1000 V peak continuous. Accuracy for dc voltage measurements ranges from 0.04 percent of reading on the 200 mV and 2 V ranges; and 0.05 percent on 20, 200 and 1000 V ranges. Overload protection permits 1000 V dc and 1000 V peak ac continuous. Frequency measurements are accurate up to 200 kHz. Voltage measurements in the dBm mode are referenced to 600 Ω ; in the decibel mode, measurements are relative to an operated selected reference level. The DMM is capable of resistance measurements up to 300 MΩ. The multimeter also has the ability to store any input as an offset or a relative reference value.

Current Measurements

An accurate current measurement is often more difficult to make than a voltage measurement. This facility has several current measuring devices. For ac current measurements, several different Pearson current monitors and various coaxial shunts are available. A current transformer is available for use with the Yokagawa power meter.

The Pearson current monitors are capable of monitoring and measuring current waveforms and amplitudes. Current, whether in the microampere or megaampere range, from 1 Hz to 1 MHz, can be measured by these devices. The monitor, which can be used in both high and low voltage circuits, is placed around the current carrying conductor. A field is induced in the core of the monitor, which in turn, induces current flow in the monitor's internal circuitry. The voltage drop across the monitor's output resistor is proportional to the current being measured. The voltage waveform is comparable to the current waveform, within the droop and rise time specifications of the monitor. These monitors are an excellent means of measuring and monitoring current because the actual circuit remains electrically isolated from the monitor. Table III includes the specifications of the monitors.

TABLE III. - SPECIFICATIONS FOR PEARSON CURRENT MONITORS

Model	Output V/A	Maximum peak I	Droop percent, μsec	Useable rise time, nsec	IT maximum, A/sec	Maximum RMS I	3 dB points		I/F peak-amps, Hz
							Low	High	
110	0.1	5 000	0.0008	20	0.5	65	1	20	1.5
411	.1	5 000	.0009	20	.2	50	1	20	.6
1025	.025	20 000	.1	100	.5	100	400	7	4.4
4418	.001	50 000	50	200	6	400	0.7	2	40

Power Meters

The Yokagawa Digital Power analyzer model 2533-13 is a three phase, 4-wire power meter capable of measuring up to 12 kW over a frequency range of 10 to 20kHz. The analyzer can measure voltage, current and power in a single or three-phase circuit. In addition, apparent power, reactive power, phase and frequency are computed. The maximum voltage allowed is 600 V ac, the maximum current is 20 A. However, with the addition of a potential transformer and/or a current transformer, scaling factors can be entered into the analyzer and then measurements can be made in circuits which exceed the limits of the analyzer. The analyzer has an analog output and a General Purpose Interface Bus, IEEE 488 (GPIB), for remote control operation.

Oscilloscopes

An oscilloscope is a vital instrument to any research facility. The value of being able to view the waveforms of an electrical circuit cannot be ignored. An oscilloscope is essential when troubleshooting a circuit as well.

The Tektronix model 7904 is a solid state oscilloscope for general purpose applications. This mainframe has four plug-in compartments and accepts any Tektronix series 7000 plug-ins. This arrangement permits flexibility for a wide range of measurement applications. The 7904 is equipped with its own calibrator and has an operating bandwidth from dc up to 5000 MHz, depending on the plug-in unit selected. The scope has a Polaroid camera attachment.

The Nicolet model 4904 is Digital Storage Scope, capable of storing up to 32 waveforms in its own memory (16 k words). The 4904 has the firmware to execute various arithmetic functions including subtraction, inverting, and data move. The most attractive feature of the oscilloscope, is the software that is available for use with the scope. Various math functions can be used to manipulate the waveforms. The unit is equipped with two 5-1/4 in. disk drives. Waveforms can be captured and then stored on a floppy. This data can be retrieved later and then manipulated by the various software packages available. The 4904 also has both an IEEE 488 and an RS-232C interface.

The Hitachi V-209 oscilloscope can be operated with ac line, external dc source or with a battery-pack. Floating measurements can be made with the Hitachi scope. It has a bandwidth from dc to 20 MHz and has a maximum sensitivity of 1 mV/div. The maximum allowable input is 250 V (dc + peak ac).

Partial Discharge Test Equipment

The presence of a partial discharge within a dielectric will, over time, lead to material degradation and ultimately, failure of the insulator. The evaluation of materials and components to be used for long periods of time in Aerospace Electrical Power Systems is essential. Test equipment is available at this facility for performing partial discharge measurements and breakdown testing of such materials and components.

The Biddle Partial Discharge (Corona) Test Set operates from a 115 V, single phase 60 Hz line voltage. Test voltages up to 40 kV, 60 Hz and 50 kV, dc are available within the unit's interlocked hi-voltage test area. This equipment is calibrated to be essentially free of internally induced Corona. A partial discharge no greater than 1.0 pC at rated voltage is specified for this unit. The detection circuitry is sensitive to 1 pC of charge. The unit is equipped with an oscilloscope for viewing of the partial discharge pulses. Three displays are available; circular, for measurement of the phase location of the pulse, an elliptical display for enhanced viewing of the test sine wave peak where discharge is most likely to occur, and a flat display for easier measurement of pulse magnitude. This versatile instrument is useful when evaluating dielectric materials and various electrical components, such as Roll Rings and capacitors.

VACUUM FACILITY WITH RESIDUAL GAS ANALYZER

One of the most attractive features of the Component Test Facility is its vacuum system (fig. 3). Bell Jar 10 (volume = 4 ft^3) is capable of a base pressure of 1×10^{-7} torr. It can be operated in either a manual or automatic mode. The system is equipped with water-cooling for components under test, thermocouples for temperature monitoring, a neon gas system and a Dycor residual gas analyzer with a Faraday Cup Detector for outgassing measurements. The RGA is equipped with analog, linear, tabular and present-time settings, for tracking 1 to 200 amu. The partial pressure specification is 1×10^{-10} torr. The present-time setting permits tracking of five operator selected gases for a maximum time span of 8 hr. The printer provides a hard copy of the screen display.

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Figure 3. - Vacuum-RGA system for outgassing tests of components.

EMI FACILITY

An R.F.I. solid metal, inside bolted, shielded enclosure (10 ft 8.5 in. by 8 ft 8 in. by 14 ft 1/2 in.) provides an environment free of radio interference where accurate measurements of a desired signal can be made. A Hewlett-Packard spectrum analyzer used with various antenna and other pick-up devices, provides a frequency spectrum of the EMI radiation of a component under test. See figure 4 for photo of facility.

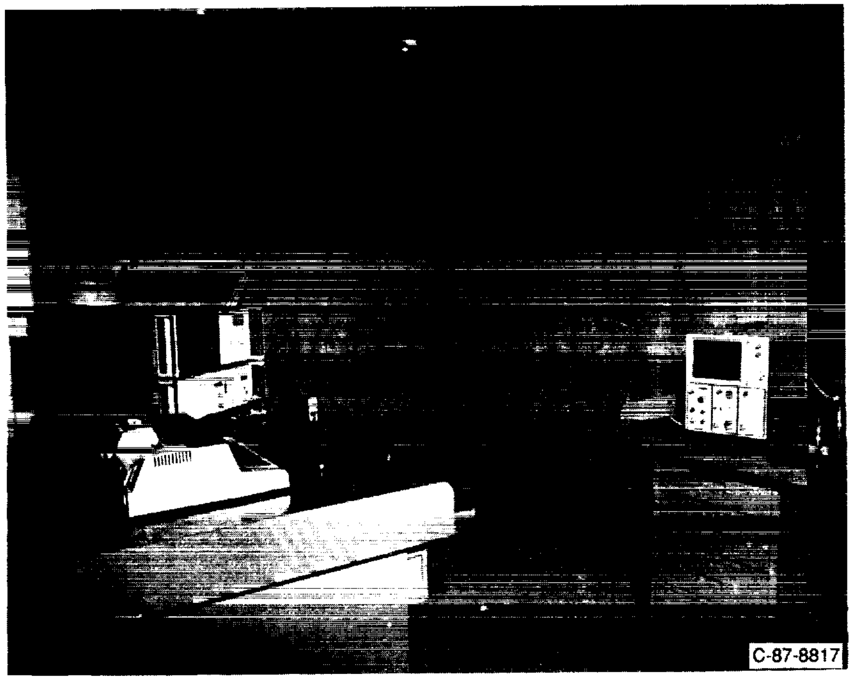

Figure 4. - Screen room for EMI comparison test (shielded enclosure).

DISTRIBUTION SYSTEM

A high frequency, high power distribution is present for the transmission of 20 kHz power throughout the facility. Various standard coaxial cables (RG 213, 218, 59) and nonstandard coaxial cables (Litz cables - 12, 8, 4 AWG equivalent) have been incorporated into the system. Other transmission lines include a Flat Litz construction by Induction General and a flat strip line construction by Gore Technology. The maximum voltage of this system is 1000 V, the maximum current is 60 A.

ADDITIONAL SYSTEMS AND FEATURES

Several different load banks, including noninductive loads are available. Maximum power rating is 50 kW. Water cooling is often necessary when dealing with such high power levels. The test facility has a city water system for cooling components and loads. A portable closed cooling heating system is also available. The Forma Scientific Model 2161/2167 is a Refrigerated and Heated Circulator Bath. This system will maintain a constant temperature in a 9.7 gal capacity and has temperature control sensitivity of ±0.02 °C over a range of -40 to 100 °C. The IEH 100 kW source has its own internal deionized water closed system for cooling. This system can be tapped into when necessary. A nitrogen gas system (20 psi) is also present.

CONCLUSION

The high power, high frequency component test facility is a vital element in the program for the development of high frequency, high power space applicable technologies. This facility is equipped for a wide range of testing applications. A power distribution network, incorporating several different power sources, allows flexibility in a testing program. Short term and long term testing is possible. Instrumentation with a high degree of accuracy is available. A vacuum facility and a shielded enclosure round out the main elements of this facility. This facility has accommodated many important test programs: 20 kHz power transformer, roll ring, preliminary testing of remote power controller. More programs are in the future.

NASA National Aeronautics and Space Administration	Report Documentation Page	
1. Report No. NASA TM-102500	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle High Power, High Frequency Component Test Facility		5. Report Date February 1990
		6. Performing Organization Code
7. Author(s) Mary Ellen Roth and Walter Krawczonek		8. Performing Organization Report No. E-5297
		10. Work Unit No. 506-41-41
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

NASA-Lewis Research Center has available a high frequency, high power laboratory facility for testing various components of aerospace and/or terrestrial power systems. This paper describes this facility, detailing all of its capabilities and potential applications.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
High frequency; Power components; Test; Evaluate; Transmission lines; Transformers; Switches		Unclassified – Unlimited Subject Category 33	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 12	22. Price* A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161