(NASA-CR-174106) INVESTIGATION OF RF EXCITED CW CO2 WAVEGUIDE LASERS Progress Report (Maryland Univ.) 26 p HC A03/MF A01
CSCL 20E
N85-13221
Unclas
G3/36 12414

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INVESTIGATION OF RF EXCITED CW CO_2 WAVEGUIDE LASERS

Progress Report
for

NASA Grant NAG5-263

Submitted by

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November 1984

INTRODUCTION

At the present time, we are able to produce RF excited 2 to 3W CW CO_2 waveguide lasers with lifetimes of the order of 10^4 to 2.10^4 hours. These results have been achieved with CO and N_2 bearing gas mixtures and with internal as well as external discharge electrodes. It should be carefully noted that these tests have been conducted with unstabilized lasers which drift around in their signatures. For this reason, the average power output was reduced to about one-half of the highest peak power output in the signature.

A very important contribution is the fact that one of the lasers, #1.1, still shows 60 percent of its original output power after it was cycled on and off every ten minutes for more than 50,000 times.

We have also begun to measure the starting voltage and driving point impedance of the RF excited gas discharge structure for different gas pressures and mixtures. This type of data will later serve as a basis for the matching and starting network optimization. Work on the ceramic local oscillator laser structure is progressing slowly. The second laser body was successfully frit- and indium-sealed. To our dismay, we later found a vacuum leak between the bore and electrode holes. The leak seems to be due to a defect or crack in the BeO body.

LIFE TEST RESULTS

Life test results are shown in figures 1 to 8, and the design parameters of the lasers involved are shown in table 1. Failure analysis results of some of the lasers, such as laser #8, which could not be restarted, will follow in our next report.

We have come to the conclusion that a proper failure analysis requires complete gas analysis results and should cover all of the original mixture constituents as well as possible impurities, such as H_2O. This analysis has to be performed in suitable intervals as the laser ages. Proposals for purchasing the required equipment to accomplish this task have been submitted.

RF IMPEDANCE MEASUREMENTS

These measurements are intended to furnish data that will serve as a basisfor the matching and starting network calculations.

TEST PROCEDURES

The actual laser discharge is first matched with a helical auto-transformer and π-network to the 50 ohm line. Matching is achieved by adjusting the π-network until the apparent SWR on the slotted line is better than 1.01 for each given input power level. Figure 9 shows the equipment used for this measurement. The auto-transformer is then removed from the laser and attached to a test fixture that closely duplicates the laser structure and brings the driving point connection out through the HP 11566A 10 cm precision airline as shown in figure 10. Pictures of the coupling networks, text fixture, and laser with observation window are shown in the appendix.

Both the π-network and 10 cm airline have APC-7 precision connectors that serve as the two reference planes for the S-parameter measurements. These measurements are performed on HP 8409 or HP 8510 network analyzers.

The four S-parameters allow one to calculate the efficiency, driving point voltage, and impedance of the network at the input power level the network was tuned for. Figures 11 and 12 show preliminary curves of the input conductance for two different gas mixtures.

The calculated voltage is then used to calibrate the voltage measured with the probe of an HP 8405A vector voltmeter. This probe is coupled through stray capacitance to the driving point of the laser as indicated in figure 10. This calibrated probe can now be used to measure the voltage required for starting the discharge. Figures 13 and 14 show this starting voltage and the minimum power required to spread the discharge over the full bore length for different pressures and gas compositions.

MEASUREMENT ACCURACY

We have varied each one of the amplitudes and phases individually in order to determine how much S-parameter amplitude and phase errors affect the calculated load impedance and network efficiency. Data for variations around a set of four typical S-parameters is presented in table 2. These results show that the S_{21} parameter amplitude precision is extremely important. Our variation of 0.1 db is realistic and perhaps even optimistic in view of the fact that the National Bureau of Standards is capable of measuring S_{12} and S_{21} parameters with 0.03 db and S_{11} and S_{22} parameters with 0.05 db precision. The network analyzers source mismatch and a network that has to be measured under almost totally reflecting conditions are the main causes for this error.

It can be shown that errors caused by the remaining SWR after tuning the networks are less important.

We have also measured the current waveform through a test discharge tube. The tube was designed with two parallel, 20 mm long, 1.5 mm nickel wire electrodes, with 3.5 mm center-to-center spacing. Its gas filling consisted of 125 torr He:CO_2:CO:Xe in the ratios 3:1:1:0.25. A parallel inductance tuned out the capacitive current through the 2 pf electrode capacitance.

The 70 MHz discharge current waveform is shown in figure 15 and clearly indicates some distortion in the peaks. Figure 15 also shows that this mostly odd order harmonic distortion is not present in the transmitter output. Because of this distortion, it does not make sense to spend a great deal of effort to further reduce the network analyzer errors.

NETWORK EFFICIENCY

Lack of impedance data forced us to design our network empirically. Our choice of reasonably good components generally resulted in network efficiencies of the order of 80 percent to 90 percent. We have also found that we sometimes had large circulating currents that lowered the efficiency to 70 percent or less. This result was not simply due to network analyzer error as there was a substantial temperature rise of some of the network components. To substantiate this statement, we show in the appendix a picture of the discolored, oxidized, tin-plated copper coil in the π-network. The input power used was only 30 watts at 140 MHz. This result should serve as a warning that an improperly designed network, placed inside the laser and surrounded by the gas mixture, can actually reduce the laser life by consuming oxygen for its oxidation.

We have found that minor design changes, such as varying the tap of the autotransformer by a fraction of a turn, can improve the efficiency to an acceptable value.

CERAMIC BeO STRUCTURE

Work on the ceramic BeO local oscillator structure is slowly progressing. The first attempt to frit- and indium-seal the structure left leaks in the indium seals of the end plates.

The second attempt was successful as far as the seals are concerned. However, a leak between the main bore and the electrode holes was discovered, indicating a flaw or crack in the very thin walls between these holes. With this possibility in mind, we are now forced to frit-seal the electrode feeder holes instead of the electrode hole ends. This will be a considerably harder task to accomplish.

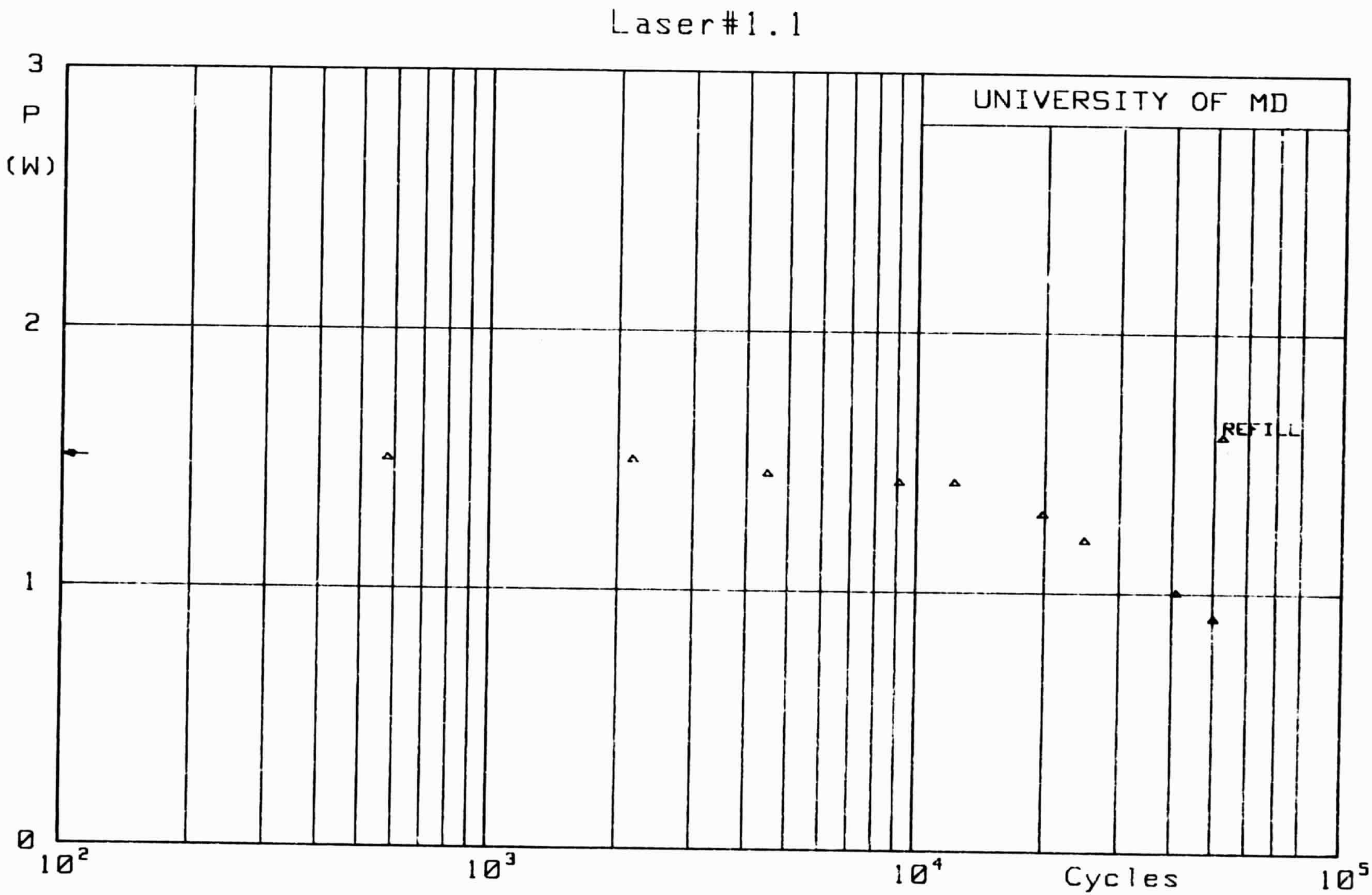


Fig.1 ,Output Power vs # of Cycles (5 min.ON,5 min.OFF)

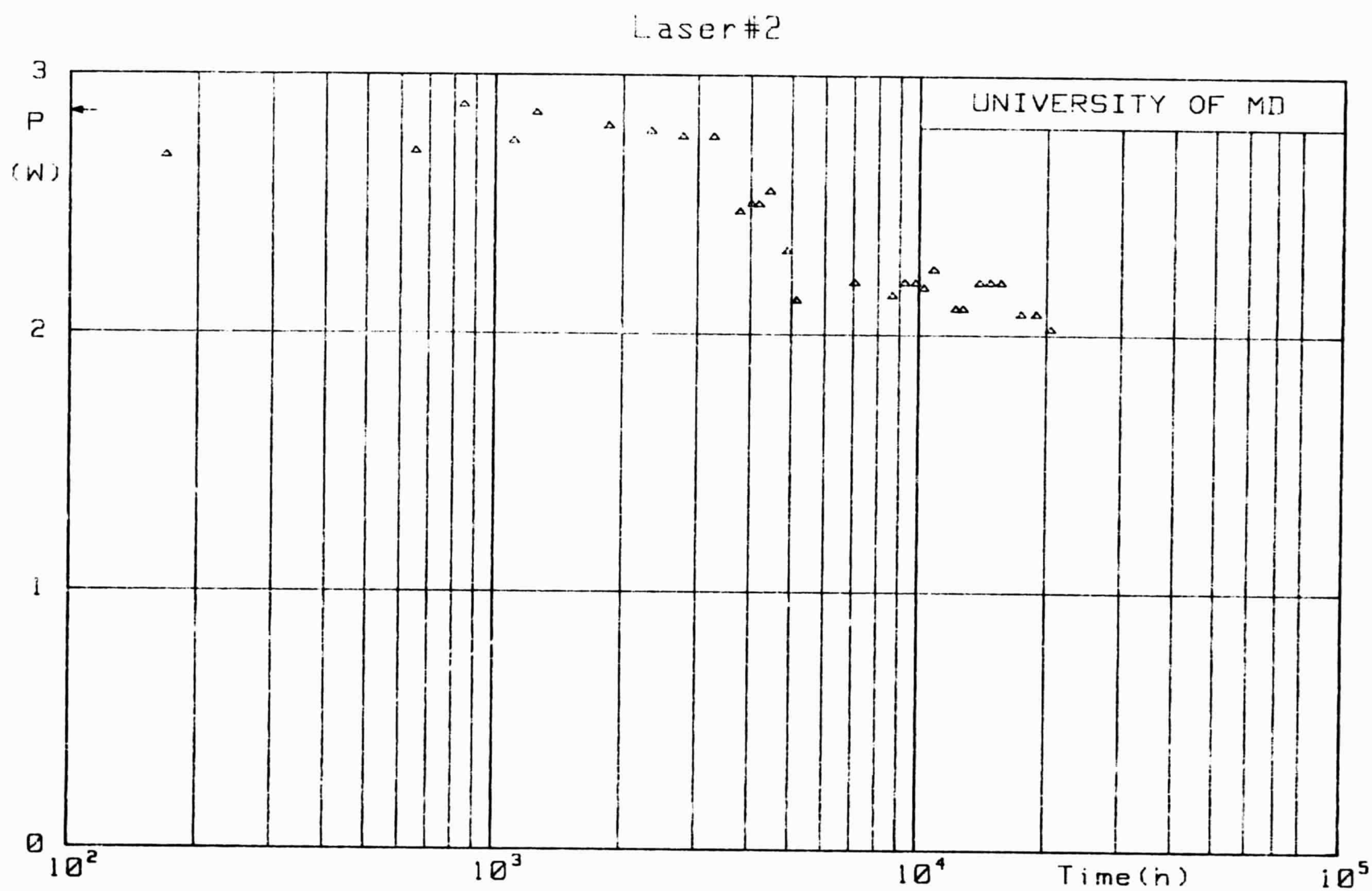


Fig.2 , Output Power vs Time

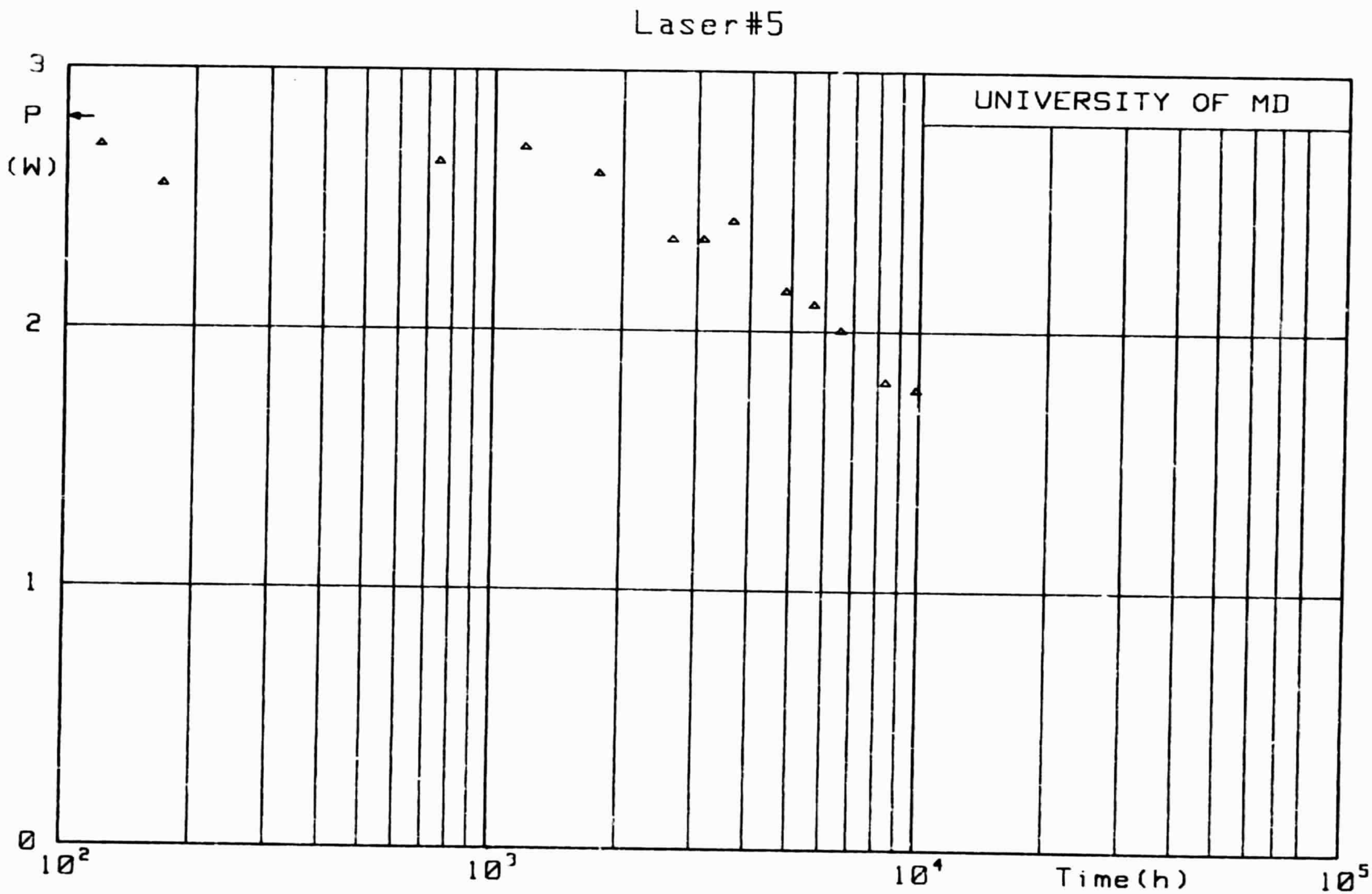


Fig.3 , Output Power vs Time

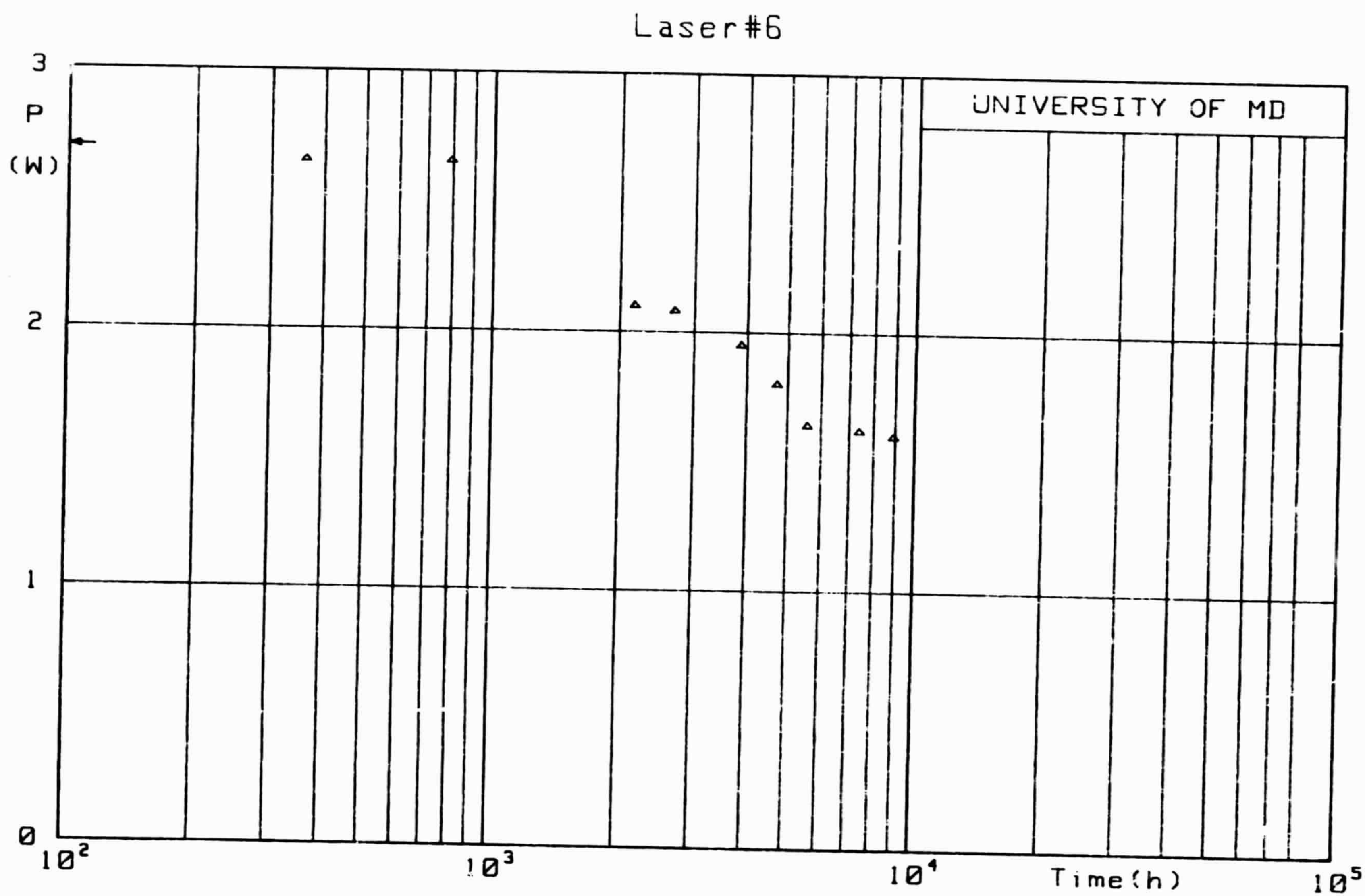


Fig.4 , Output Power vs Time

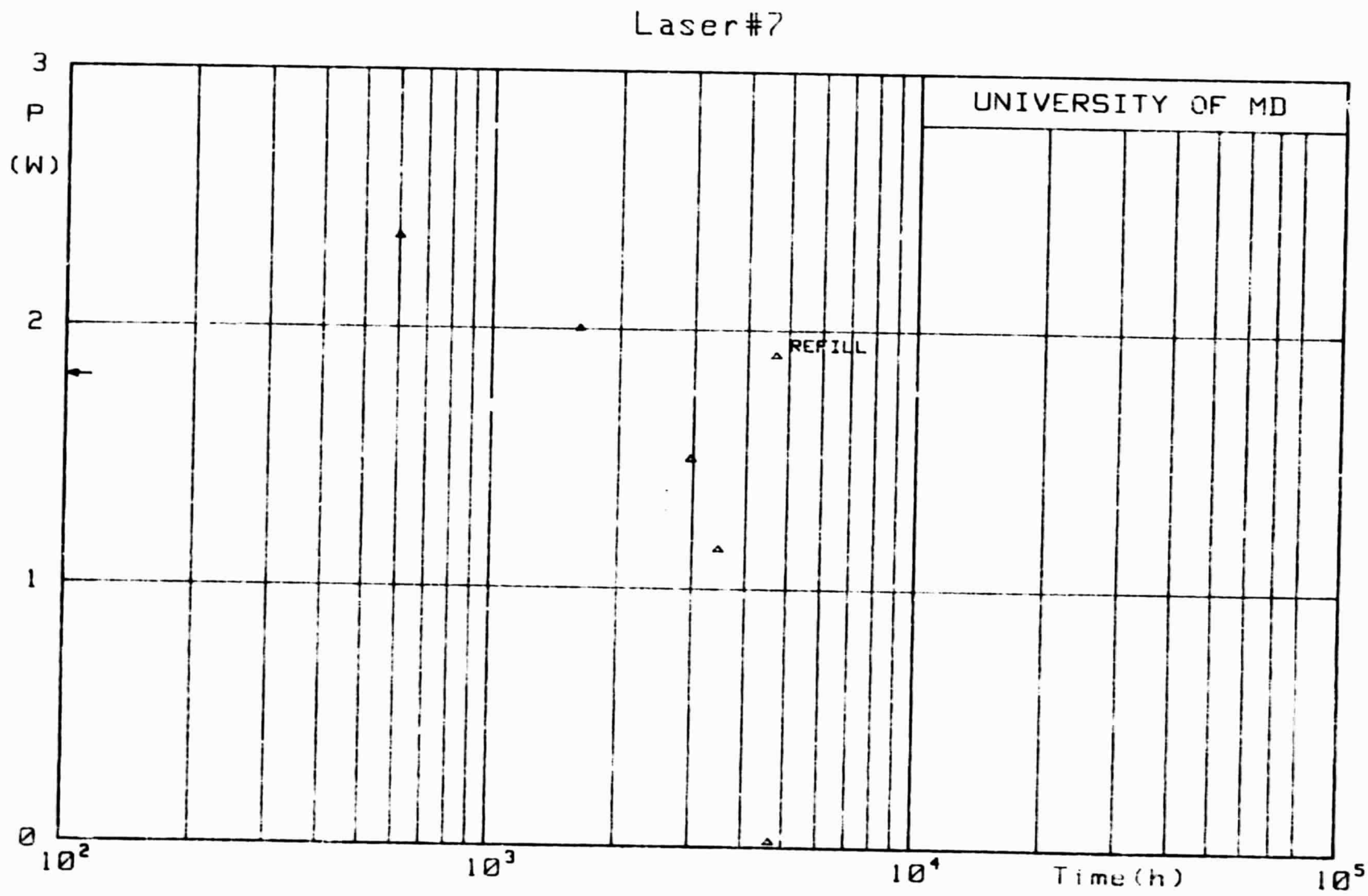


Fig. , Output Power vs Time

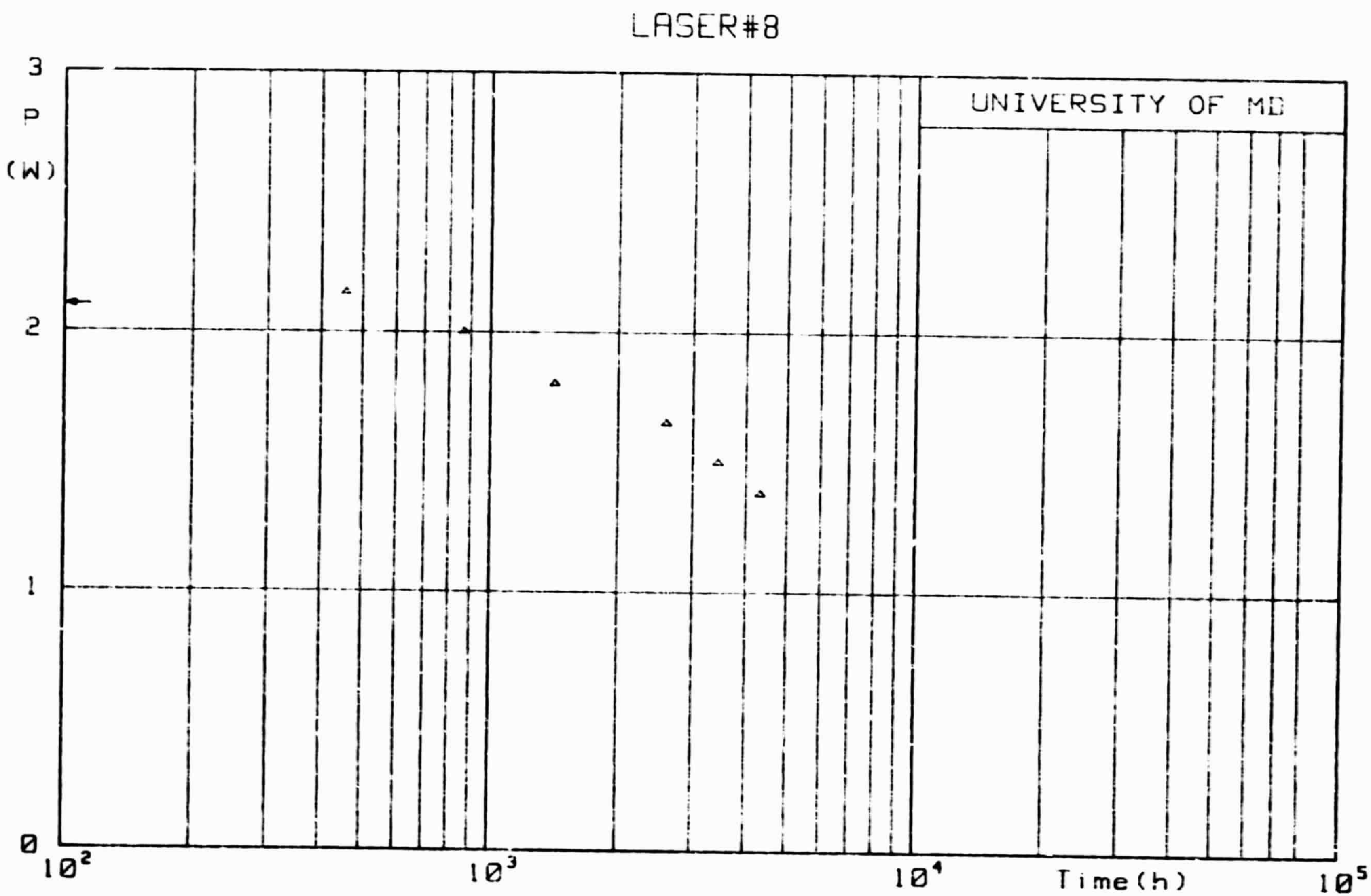


Fig.6 , Output Power vs Time

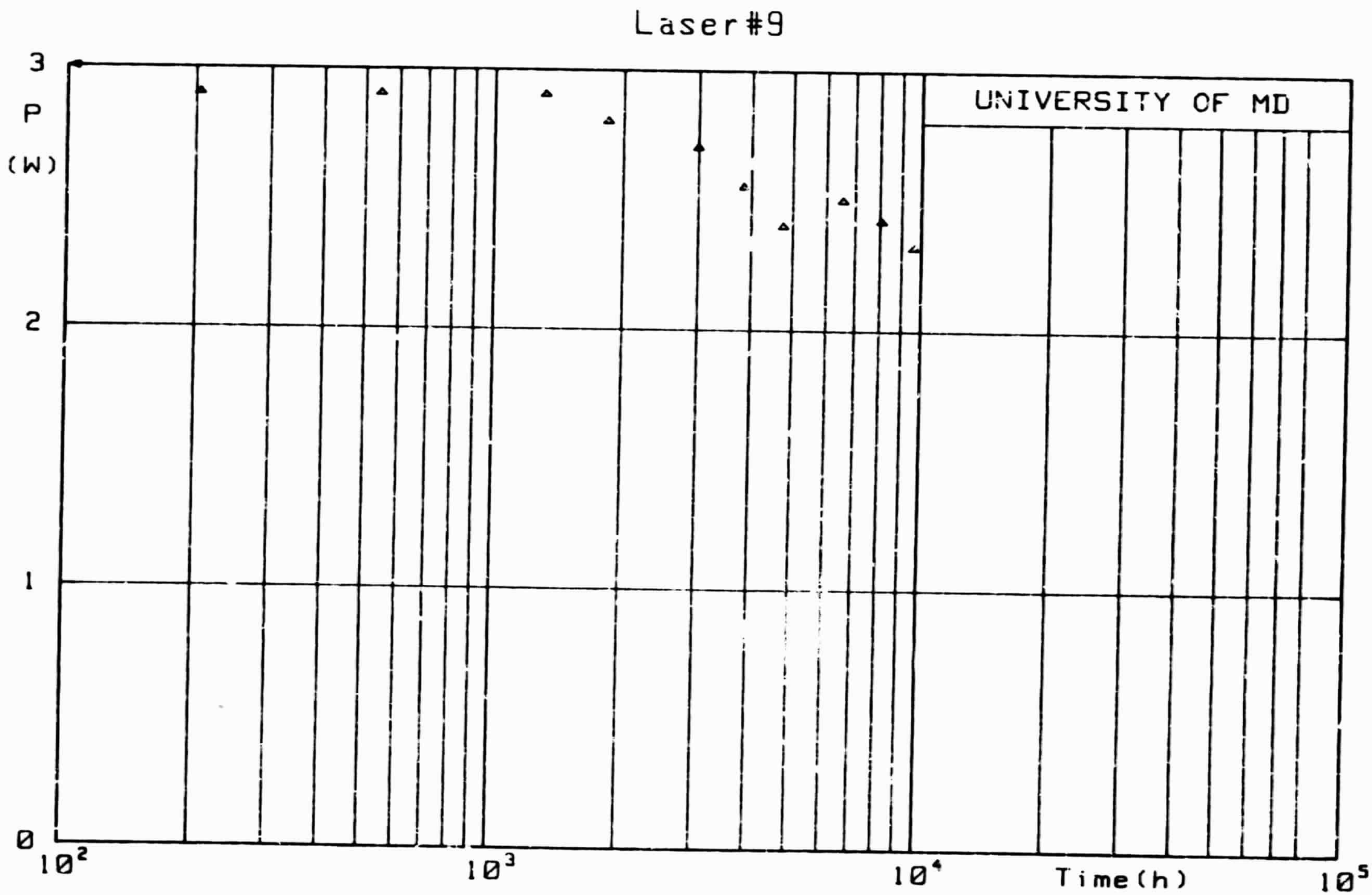


Fig.7 , Output Power vs Time

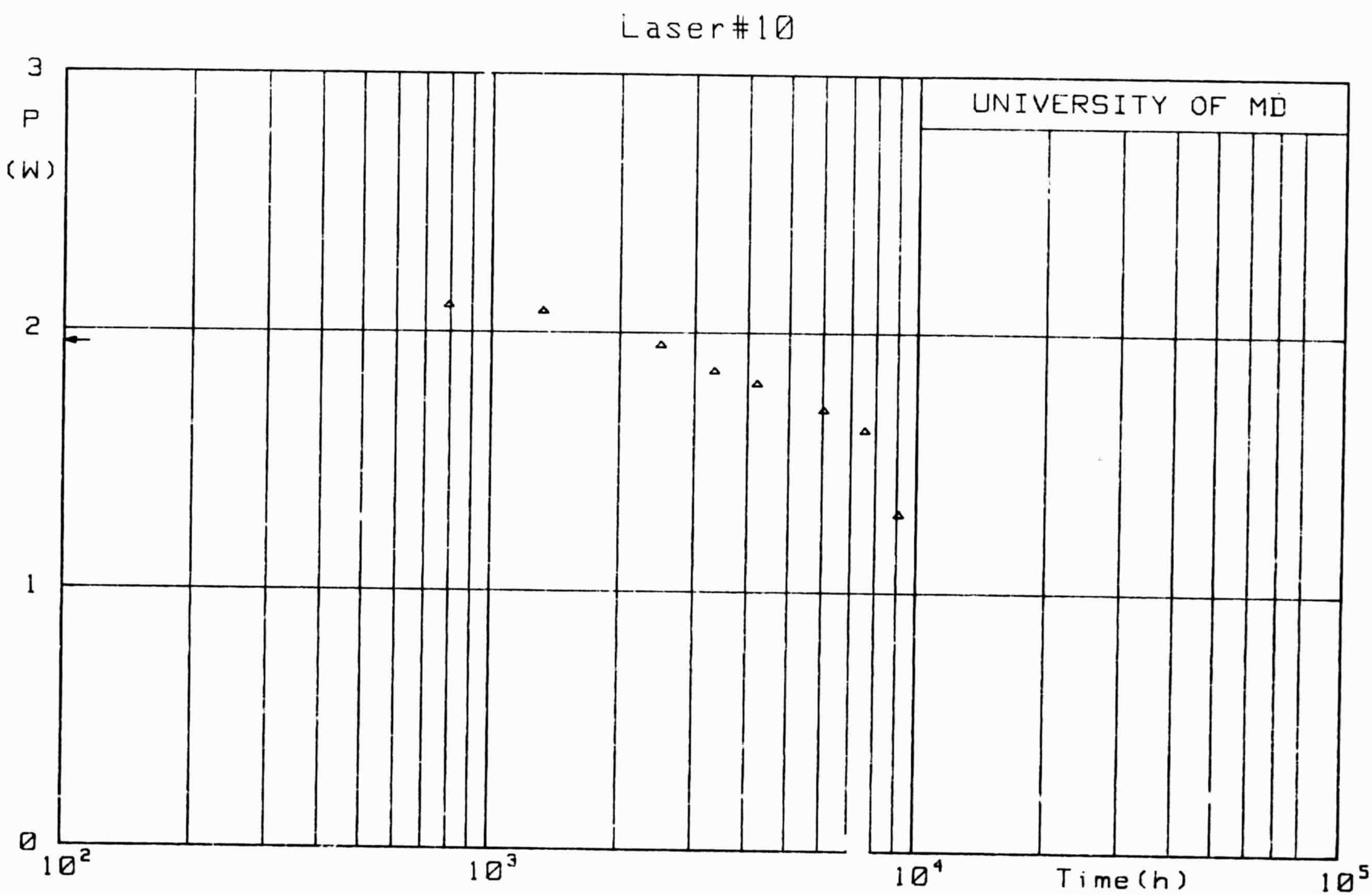


Fig.8 , Output Power vs Time

Table 1

LASER	HOUSING MATERIAL	TOP-ELECTRODE	BOTTOM-ELECTRODE	GAS-MIXTURE He	CO_2	CO	N_2	Xe	OUTPUT-MIRROR	REMARKS
# 1	Cu	BeO	Pt	3	1	1	0	.25	.94 at 9.6u	
# 1.1	Cu	BeO	Pt	3	1	1	0	.25	.94 at 9.6u	Refilled #1, run on ON-OFF cycle
# 2	Cu	BeO	PT, 4% Cu	3	1	1	0	.25	.94 at 9.6u	
# 5	Au plated Cu	BeO	Pt	3	1	1	0	.25	.934 at 10.6u	
# 6	Au plated Cu	BeO	BeO leaf	3	1	1	0	.25	.94 at 10.6u	
# 7	Au plated Cu	BeO	BeO leaf	3	1	.5	1	.25	.928 at 10.6u	
# 8	303 SS	BeO	303 SS	3	1	1	0	.25	.934 at 10.6u	
# 9	303 SS	BeO	Pt	3	1	.5	1	.25	.935 at 10.6u	
# 10	303 SS	BeO	BeO leaf	3	1	.5	1	.25	.934 at 10.6u	

RF Excitation: 30 W at 140 MHz
Laser bore: 1.5mm wide, 1.65mm high, 152.4mm long, 127mm excited
Internal mirror spacing 153mm, dielectric total reflector on Si, coated ZnSe output coupler (III-VI)
Gas volume 100cc, pressure 120 Torr

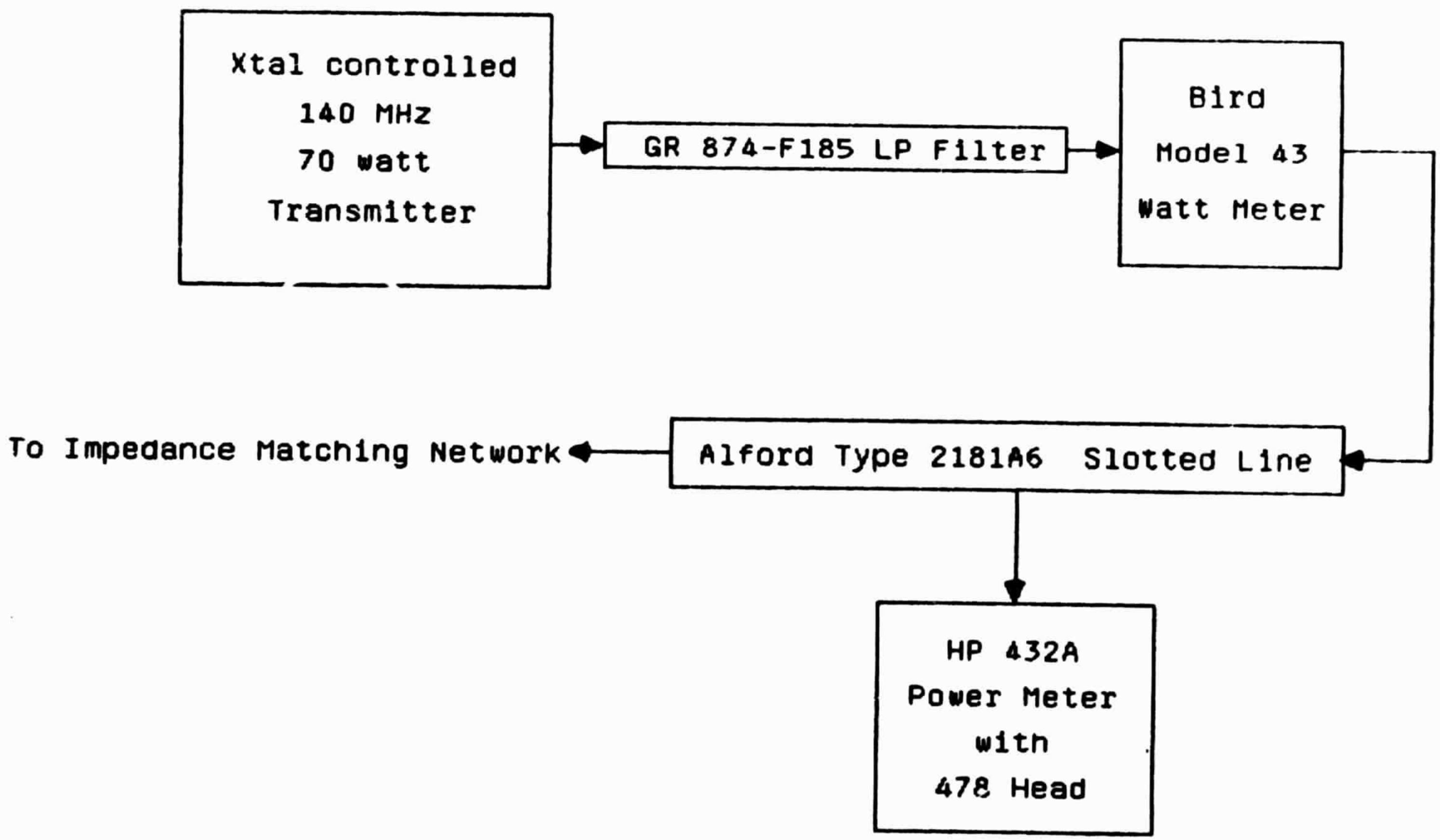


Figure 9, Equipment configuration for SWR measurement

Plasma Impedance Measurement

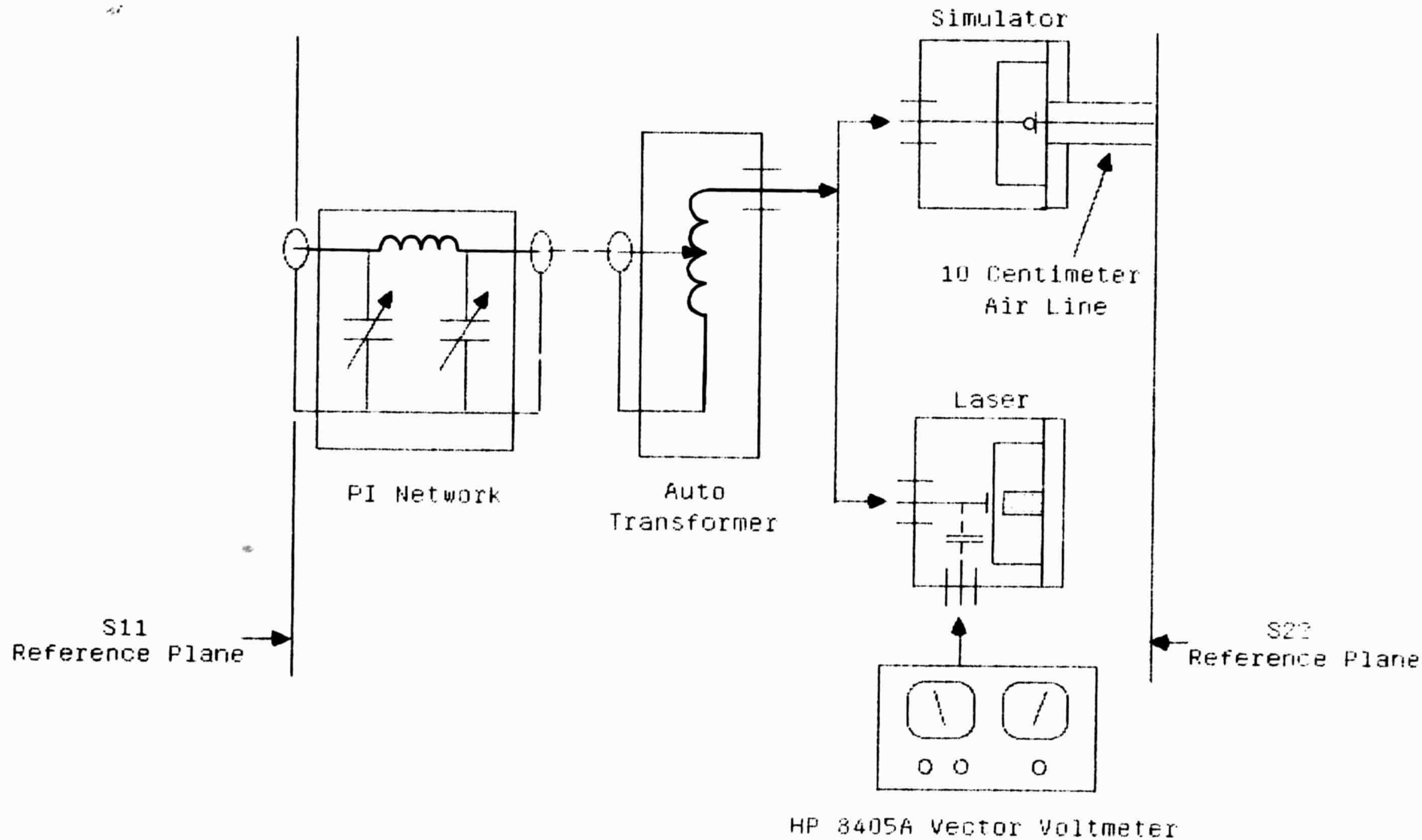


Figure 10, Experimental Setup

He:CO2:CO:Xe ; 3:1:1:.25

Laser bore:1.5mm wide,1.65mm high,152.4mm long,127mm center-excited at 140 MHz

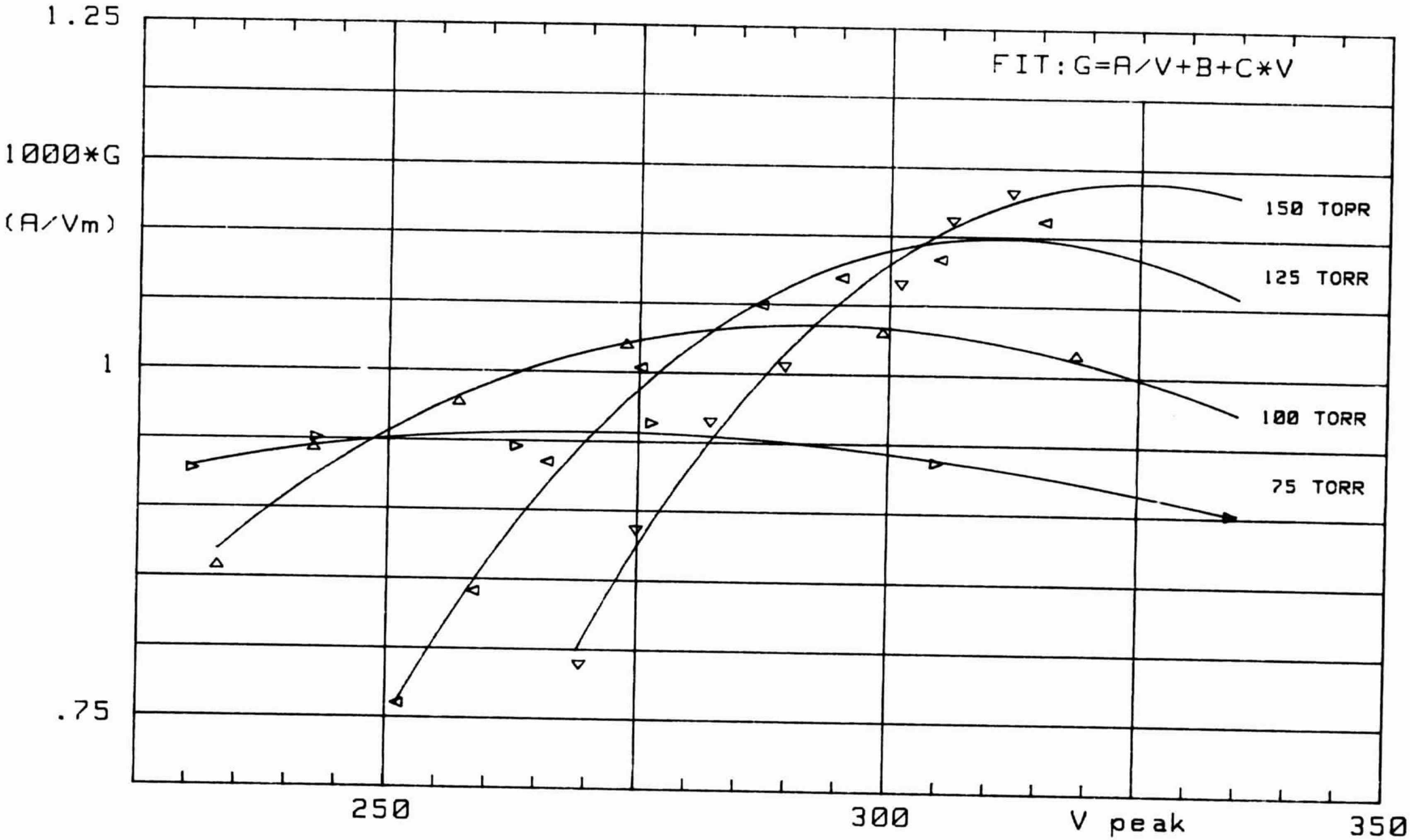


Fig.11, CENTER RF-CONDUCTANCE

He:CO2:N2:Xe ; 3:1:1:.25

Laser bore:1.5mm wide,1.65mm high,152.4mm long,127mm center-excited at 140 MHz

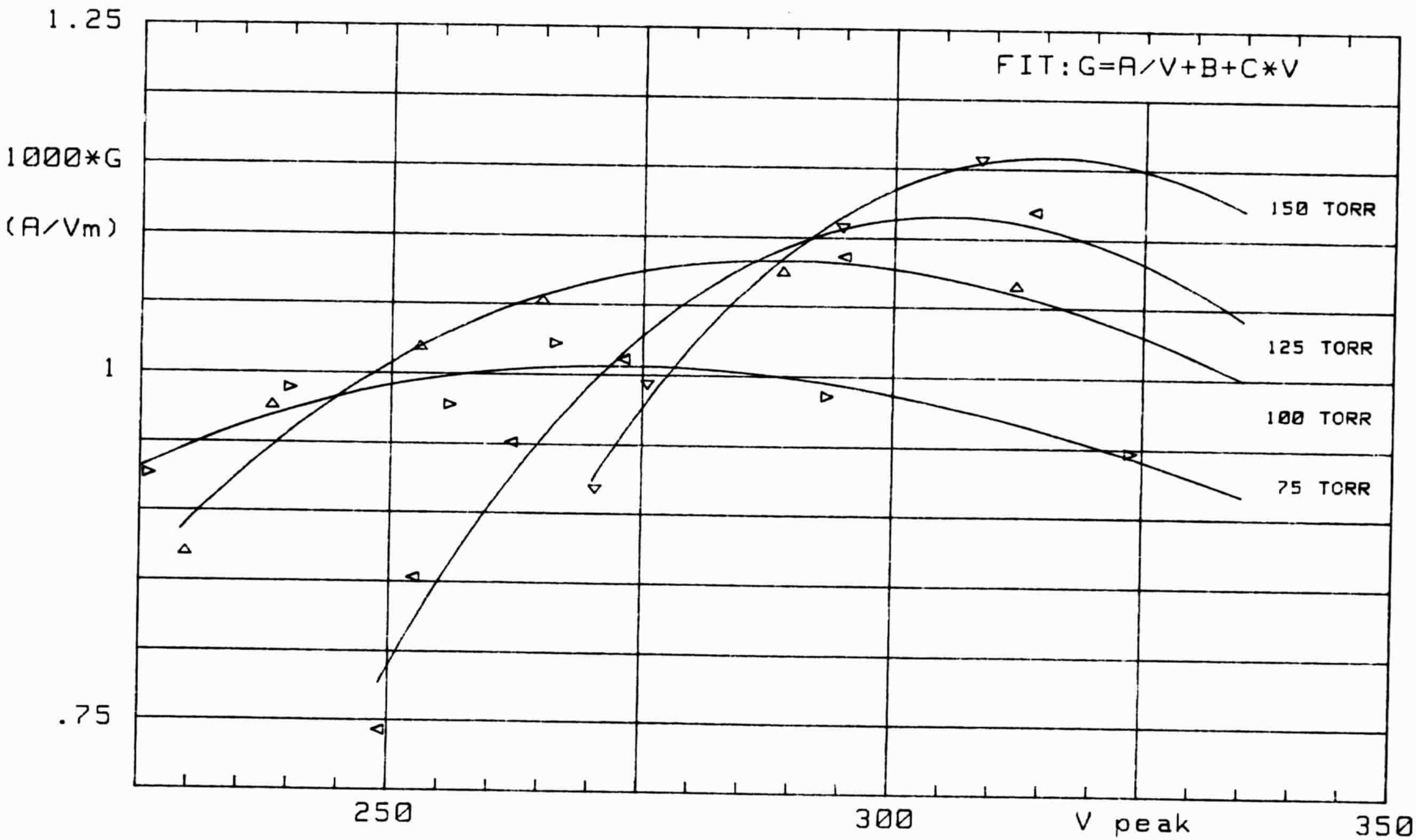


Fig.12 , CENTER RF-CONDUCTANCE

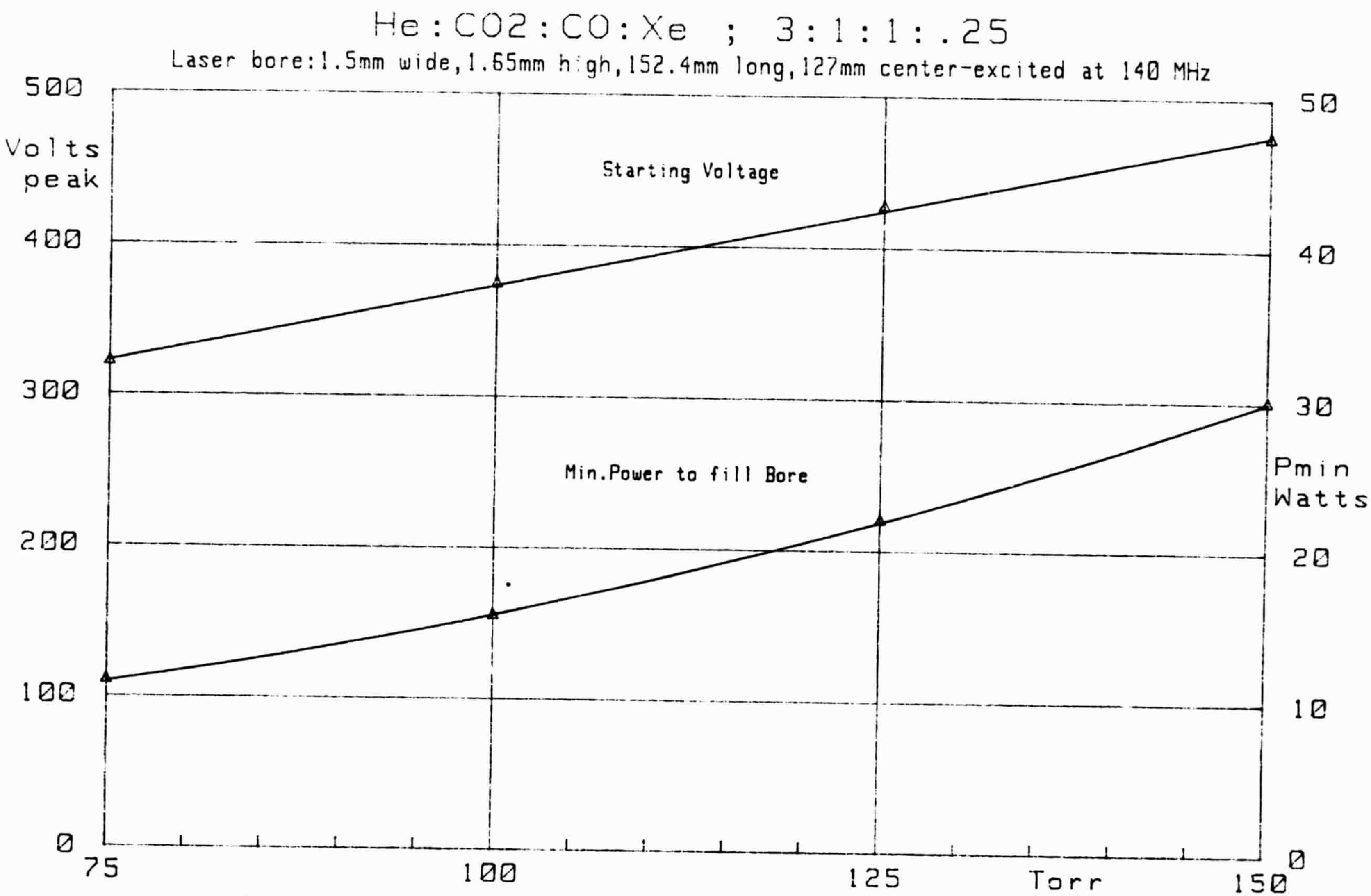


Fig. 13, STARTING VOLTAGE AND Pmin vs PRESSURE

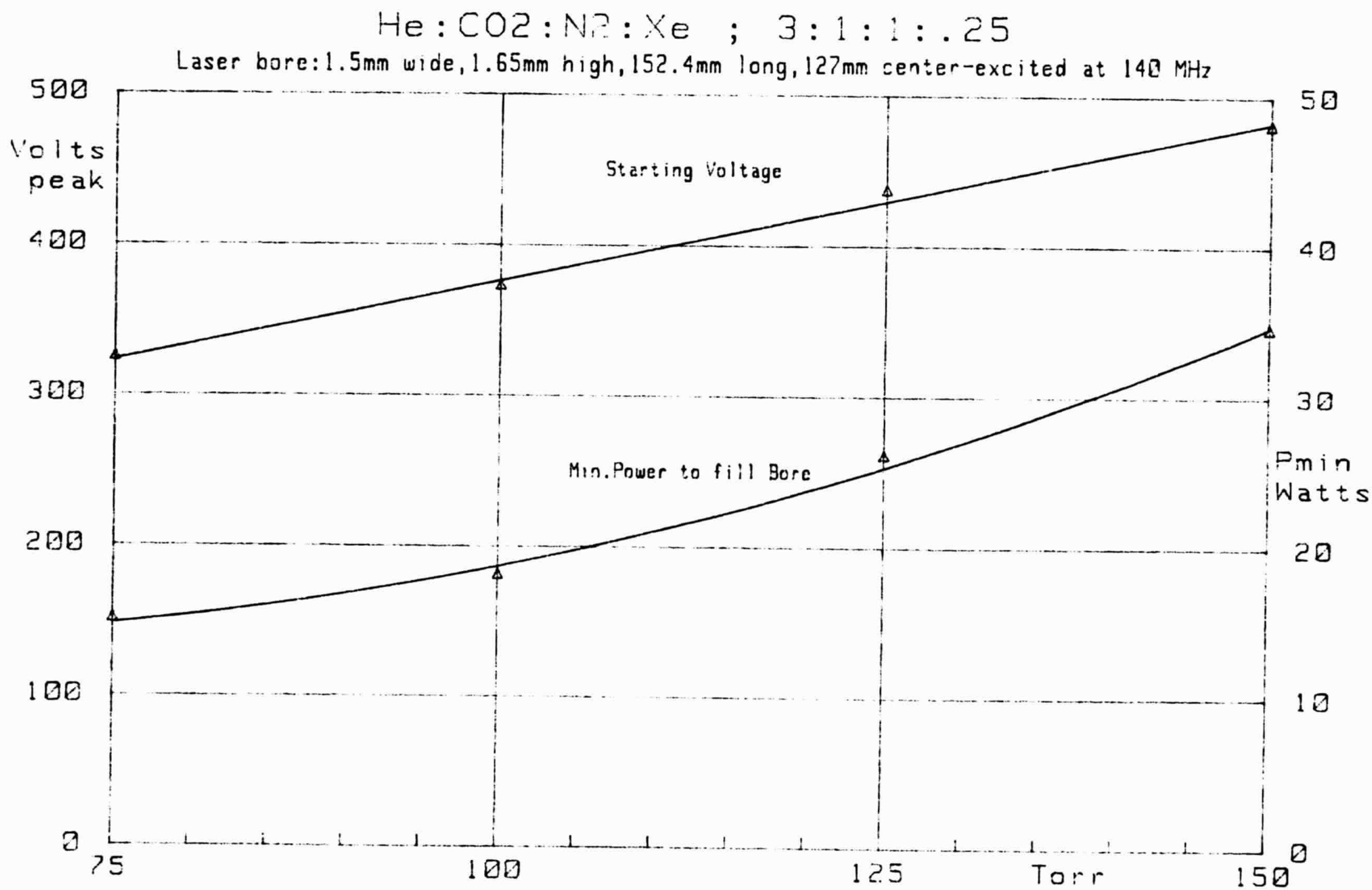
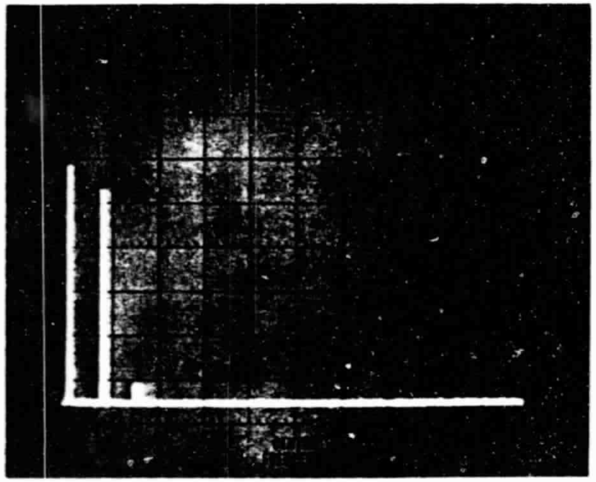


Fig.14, STARTING VOLTAGE AND Pmin vs PRESSURE

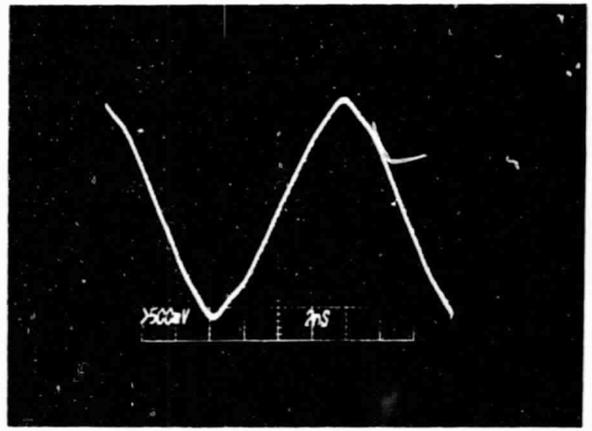
TABLE 2

S-PARAMETER MAGNITUDE				S-PARAMETER PHASE				COMPUTED VALUES		
S11	S12	S21	S22	S11	S12	S21	S22	Rp	Cp	Eff
-1.07	-9.00	-9.00	-0.65	142.5	169.7	169.7	17.9	1188.5	11.11	90.33
-1.17	-9.00	-9.00	-0.65	142.5	169.7	169.7	17.9	1162.3	11.11	90.42
-1.07	-9.10	-9.00	-0.65	142.5	169.7	169.7	17.9	1215.8	11.12	90.22
-1.07	-9.10	-9.10	-0.65	142.5	169.7	169.7	17.9	1244.0	11.12	88.03
-1.07	-9.00	-9.10	-0.65	142.5	169.7	169.7	17.9	1215.8	11.12	88.17
-1.07	-9.00	-9.00	-0.75	142.5	169.7	169.7	17.9	1392.9	11.12	76.28
-1.07	-9.00	-9.00	-0.65	141.5	169.7	169.7	17.9	1186.9	11.15	90.35
-1.07	-9.00	-9.00	-0.65	142.5	168.7	169.7	17.9	1190.8	11.08	90.25
-1.07	-9.00	-9.00	-0.65	142.5	168.7	168.7	17.9	1193.7	11.05	90.13
-1.07	-9.00	-9.00	-0.65	142.5	169.7	168.7	17.9	1190.8	11.08	90.25
-1.07	-9.00	-9.00	-0.65	142.5	169.7	169.7	16.9	1197.0	10.90	90.35

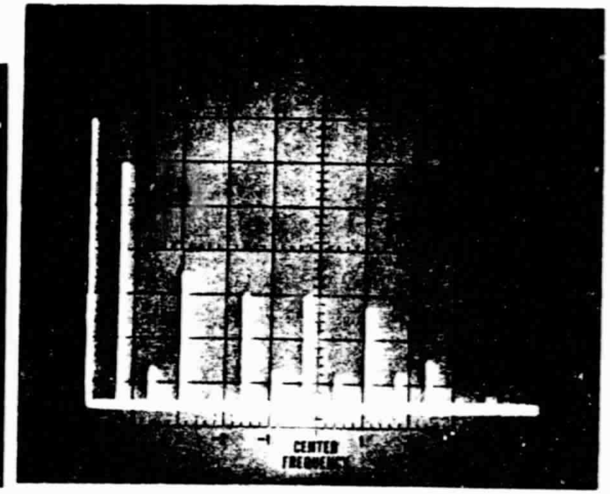
S-PARAMETER VARIATION EFFECTS



70 MHz Transmitter: Output spectrum
10db per div.



Discharge: Current waveform



Discharge: Current Spectrum
10db per div.

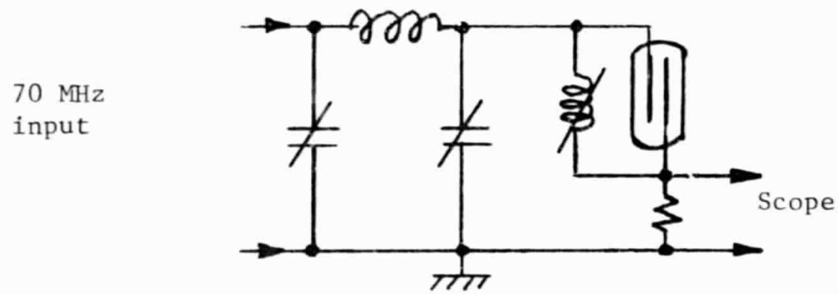


Figure 15, DISCHARGE CURRENT WAVEFORM