CALSTART

A California Non-Profit

Consortium Developing

Advanced Transportation

Technologies

April 29, 1998

Mr. John Gully
Assistant Director, Land Systems
Defense Advanced Research Projects Agency/TTO
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

Dr. Robert Rosenfeld
Program Manager
Defense Advanced Research Projects Agency/TTO
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

Re: Cooperative Agreement MDA972-95-2-0011
and modifications through P00012

Dear John and Bob:

Please find enclosed the quarterly report for the period January 1 through March 31, 1998.

If you have any questions, please call me at (818) 565-5608.

Sincerely,

Linda

Linda C. Wasley
Contracts Administrator

DISTRIBUTION STATEMENT A
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enc.

cc: E. Ely
R. Gallagher

A California Non-Profit Consortium Developing Advanced Transportation Technologies

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

ELECTRIC AND HYBRID ELECTRIC VEHICLE TECHNOLOGIES

COOPERATIVE AGREEMENT MDA972-95-2-0011 and Modifications through P00012

QUARTERLY REPORT January 1 to March 31, 1998

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HYBRID ELECTRIC BUS DEMONSTRATION

Project Manager: ***Capstone Turbine Corporation***
CS-AR94-06

Howard Longee attended a DARPA review session on April 1, 1998 at CALSTART. DARPA representatives at the review included Dr. Robert Rosenfeld, Ryan Gallagher, and Dan Jordan.

Capstone continues to demonstrate the turbo-generator on-board the AVS shuttle bus in the Chattanooga area. The bus was in regular service in Chattanooga carrying passengers during the quarter. Capstone continues to focus on improving the reliability and manufacturability of the Capstone Turbine. The existing unit continues to perform well in daily service.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Initiate Work	40,000	40,000		8/30/95	12/15/95	112,811	36,000
2	Vandenburg Combustor/Monolith Test rig	102,500	102,500		12/31/96	1/11/96	102,932	92,250
1	Hardware/Electrical Design	50,000	50,000	1	12/31/96	1/11/97	50,000	50,000
2	Vehicle Integration	82,000	82,000	2	3/30/97	3/30/97		
3	System Integration	20,000	20,000	3	6/30/97	3/30/97	107,310	90,000
4	Final report	7,500	5,000	4	9/30/97			
	TOTAL	**300,000**	**300,000**				**373,053**	**268,250**

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HYBRID VEHICLE TURBOGENERATOR WITH LIQUID FUELED CATALYTIC COMBUSTOR

Project Manager: ***Capstone***
CS-AR97-06

This project was canceled on April 1, 1998 when Howard Longee attended a review at CALSTART. Capstone has undergone a reorganization and chosen to focus their resources on the design and operation of their stationary turbine. Capstone retains a long-term interest in this technology. However, at this time Capstone believed it was better to terminate the project than to delay it for an indefinite period of time. No agreement had yet been executed between CALSTART and Capstone. DARPA representatives at the review included Dr. Robert Rosenfeld, Ryan Gallagher and Dan Jordan.

CALSTART will work with DARPA to identify other potential related projects.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Complete design/fabrication	161,000	539,750					0
2	Procure DAS. Manufacture bus and drive train	60,000	210,00[illegible]					0
3	Ship bus to transit system	6,000	35,000					0
4	Final report	75,000						0
		302,000	784,750					$0

CANCELED

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HEAVY-DUTY HYBRID ELECTRIC VEHICLE EMISSIONS STUDY

Project Manager: Natural Resources Defense Council
CS-AR94-07

Arcadis, a subcontractor to the National Resources Defense Council (NRDC) for this study, continued to work on the economic analysis during this quarter. The basic parameters for the analysis, such as range of vehicles, range of fuels, the size of the vehicles, etc., have been defined. Arcadis is now comparing capital and operating costs for the various vehicle types. This comparison is not yet complete. NRDC indicates that the study should be complete by June 1998.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Refine study design.	20,000	20,000	1	8/1/95	12/30/95	13,500	
2	Data collection	16,000	16,000	2	11/1/95	9/30/96	16,000	
3	Data Evaluation	16,000	16,000	3	2/1/96	12/30/96	23,500	63,000
4	Scientific review	16,000	16,000	4	5/1/96			
5	Draft study	16,000	16,000	5	8/1/96			
6	Final report/study	16,000	16,000	6	11/1/96			
	TOTAL	**100,000**	**100,000**				**63,000**	**63,000**

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INTERNET

Project Manager: ***CALSTART***
CS-DARO-04

Dave Sotero from CALSTART received valuable counsel on its clean car catalog from Dr. Robert Rosenfeld at the April 1, 1998 review on-site at CALSTART. Please see Appendix for view graphs presented.

Dr. Rosenfeld helped identify new categories that would make the vehicle and component catalog more usable. CALSTART is investigating ways to integrate these additional categories into the web site database.

Since the last reporting period, CALSTART has completed design work for both the public and user interfaces for the Advanced Transportation Industry Yellow Pages Database on the CALTART web site. CALSTART plans to publicly unveil the revised Yellow Pages by May 1, 1998.

Other sections of the site, including News Notes and Clean Car Catalogs will be unveiled after the Yellow Pages become public.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Upgrade CALSTART web server	30,000						30,000
2	Expand Vehicle Catalog	20,000						15,000
3	Develop component catalog	20,000						
4	Develop AT Industry FAQ	20,000						
		90,000	0					45,000

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HEAVY-DUTY VEHICLE INDUSTRY ANALYSIS

Project Manager: CALSTART
CS-AR97-12

Dr. Kevin Nesbitt discussed the study with Dr. Robert Rosenfeld of DARPA in a meeting April 1, 1998 at CALSTART.

CALSTART continues work on Task 1 and Task 3. We continue to collect data on heavy-duty hybrid electric vehicles and other advanced heavy-duty vehicle technologies likely to compete in the same markets. The data collected to date has been catalogued and entered into our electric and hybrid vehicle database. We continue to meet with key players in the heavy-duty vehicle industry, especially those directly involved with the development of heavy-duty hybrid electric vehicles. We are also actively attending workshops, seminars and conferences pertaining to ongoing developments in electric and heavy-duty vehicle technologies.

Our progress to date has given us a much better understanding of the critical trends within the industry and the factors likely to play a pivotal role in the heavy-duty hybrid electric vehicle market. CALSTART will continue on our current course of data collection and visit companies to view, in person, the most advanced hybrid electric vehicle technologies. DARPA was briefed on our progress on April 1 at the DARPA Electric and Hybrid Electric Program Review in Burbank, California. At that time the project completion date was extended to mid December 1998.

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HEAVY-DUTY VEHICLE INDUSTRY ANALYSIS

Project Manager: ***CALSTART***
CS-AR97-12

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Compilation of existing data/Update EHVTP database	40,000		**1**	3/30/98	3/31/97		40,000
2	Analysis of Technology transfer to military applications	20,000		**2**	7/30/98			
3	Evaluation of competing technologies	25,000		**3**	8/30/98			
4	Assessment of market development factors	55,000		**4**	9/30/98			
5	Final report	41,829		**5**	12/30/98			
	TOTAL	**181,829**						**40,000**

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DARPA INTERNET-BASED E/HEV PROJECT LISTINGS

Project Manager: ***CALSTART***
CS-AR97-14

CALSTART was able to meet directly with Ryan Gallagher of the Systems Planning Corporation (SPC) during the DARPA on-site review April 1, 1998. Systems Planning Corp. committed some of its resources to ensuring the success of the database implementation.

CALSTART has also begun working with its technical contractor to identify a data dictionary necessary to populate both the CALSTART and SPC database with concurrent fields via internet protocols. Once both organizations agree on the data dictionary, SPC will modify its existing databases to accommodate the concurrent fields and scripts created to transfer the data between the two databases. Work will then begin to update coalition projects via the new database interface.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Database/Interface Design	5,779		1	3/31/98	3/31/98		5,779
2	Database/Interface creation	8,529		1	3/31/98			
3	Data collection/coordination	7,282		1	3/31/98	On-going		7,282
4	Data collection/edit	13,214		2	6/30/98	On-going		4,439
5	Design graphic user interface	5,963		1	3/31/98			
6	Integrate graphics	7,445		2	6/30/98			
7	Check-off/post	7,966		2	6/30/98			
8	Maintain/train/promote 1	8,161		3	9/30/98			
9	Maintain/train/promote 2	5,661		4	12/31/98			
		70,000	0					**17,500**

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PROGRAM TO MINIMIZE LOSSES IN MECHANICAL BATTERIES FOR ELECTRIC VEHICLES

Project Manager: ***Avcon***
CS-AR95-01

Avcon has completed testing on the standard and optimized bearing during this quarter. This constitutes the conclusion of Task 9 and 10 respectively. Avcon has summarized the results of the tests they conducted in their final test report, which is included with this quarterly report.

The test results determine the effects of Eddy Current on the system. Avcon assembled the test rig and installed it in the spin pit. Avcon then spun it to a peak speed of 11,100 rpm and disengaged the motor. Avcon recorded the coast down time as well as the AC and DC currents.

Avcon ran the test fixture in two separate configurations. The first configuration was with open slots in the magnetic bearing stator, while in the second wedges were installed in an attempt to reduce eddy current losses. Avcon's tests did not show any appreciable performance difference between the two configurations. Based on data they gathered, Avcon concluded that the losses due to wind are insignificant compared to the electrical losses from the bearings, which are also small, on the order of 5 watts per bearing. Avcon believes the most probable explanation is the control coil offsets to maintain shaft position and the AC unbalance generated by control fields are far more significant than the eddy currents. Additional testing at various offset positions would be required to quantify the effect of control coil currents on system performance.

Avcon has not yet completed a final report for the entire program but will do so next quarter.

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PROGRAM TO MINIMIZE LOSSES IN MECHANICAL BATTERIES FOR ELECTRIC VEHICLES

Project Manager: Avcon
CS-AR95-01

	MILESTONE	DARPA	MATCH	DUE DATE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	1 Develop Computer Model 2 Begin Rotordynamic Analysis 3 Develop Test Plan 4 Design Test Rig	37,706	37,706	9/30/96	9/30/96	37,706	37,706
2	Complete Rotordynamic Analysis	16,220	16,220	12/31/96	12/31/96	16,220	16,220
3	Complete Test Plan 5 Begin Fabrication of Test Rig	10,160	8,470	3/30/97	3/30/97		36,276
4	Complete Fabrication of Test Rig	15,160	8,600	6/30/97	9/30/97	31,226	
5	6 Fabricate Standard Bearings 7 Design Optimized Bearings 8 Fabricate Optimized Bearings	12,182	23,618	9/30/97			
6	9 Test Standard Bearing	10,124	8,600	12/31/97			
7	10 Test Optimized Bearing 11 Iterate Computer Model	3,797	12,800	3/31/98			
8	Final Report	21,000	10,335	6/30/98	3/31/98	36,147	
		$126,349	**$126,349**			**126,349**	**85,152**

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MAGNETIC BEARING COMMERCIALIZATION PLAN

Project Manager: AVCON
CS-AR97-11

CALSTART and Avcon have not yet executed a contract. Avcon's program manager for this new project left the organization. CALSTART will be conducting a site visit with Avcon early next quarter to resolve the situation. If Avcon is still committed to the project and has the personnel to satisfactorily complete the program, CALSTART will execute a new contract. If there is a determination to the contrary, CALSTART will contact DARPA and jointly review the situation.

CALSTART

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FLYWHEEL LIFECYCLE TESTING

Project Manager: ***U.S. Flywheel Systems***
CS-AR95-02

Jack Bitterly of U.S. Flywheel Systems (USFS) provided a report on the status of this program to Dr. Robert Rosenfeld, Ryan Gallagher and Danny Jordan of DARPA during the program review held at CALSTART. Please see Appendix for slides presented on April 1, 1998.

USFS has continued work on the development of independent bearings to replace the ones which were to have been supplied by Avcon. USFS tested the data acquisition and control, vacuum, and cooling systems with the first flywheel module. Also, USFS completed modifications to module two to accept several different control systems. The data acquisition still needs to be calibrated after the flywheel module is installed. USFS hopes to start life cycle testing on the flywheel modules by July, 1998. The first test is projected for completion in October, 1998. USFS hopes to test modules 3 and 4 from November to December 1998. Next quarter, USFS will continue to work on providing functional magnetic bearings.

	MILESTONE	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Detail plan		900,000	1	7/7/96	7/16/96		
2	Fabricate flywheels	230,000	300,000	2	9/7/96	7/16/96	1,129,267	195,200
3	Design, prog. & fabricate DAS	90,000	140,000	3	9/7/96	12/2/96	318,126	171,057
4	Design/Install containment chambers	50,000	80,000	4	9/7/96	12/30/96		
5	Install modules/check system		60,000	5	10/7/96			
6	Cycle tests/statistical analysis	20,000	80,000	6	3/7/97			
7	Final report	10,000	40,000	7	6/7/97			
		400,000	**1,600,000**				**1,447,393**	**366,257**

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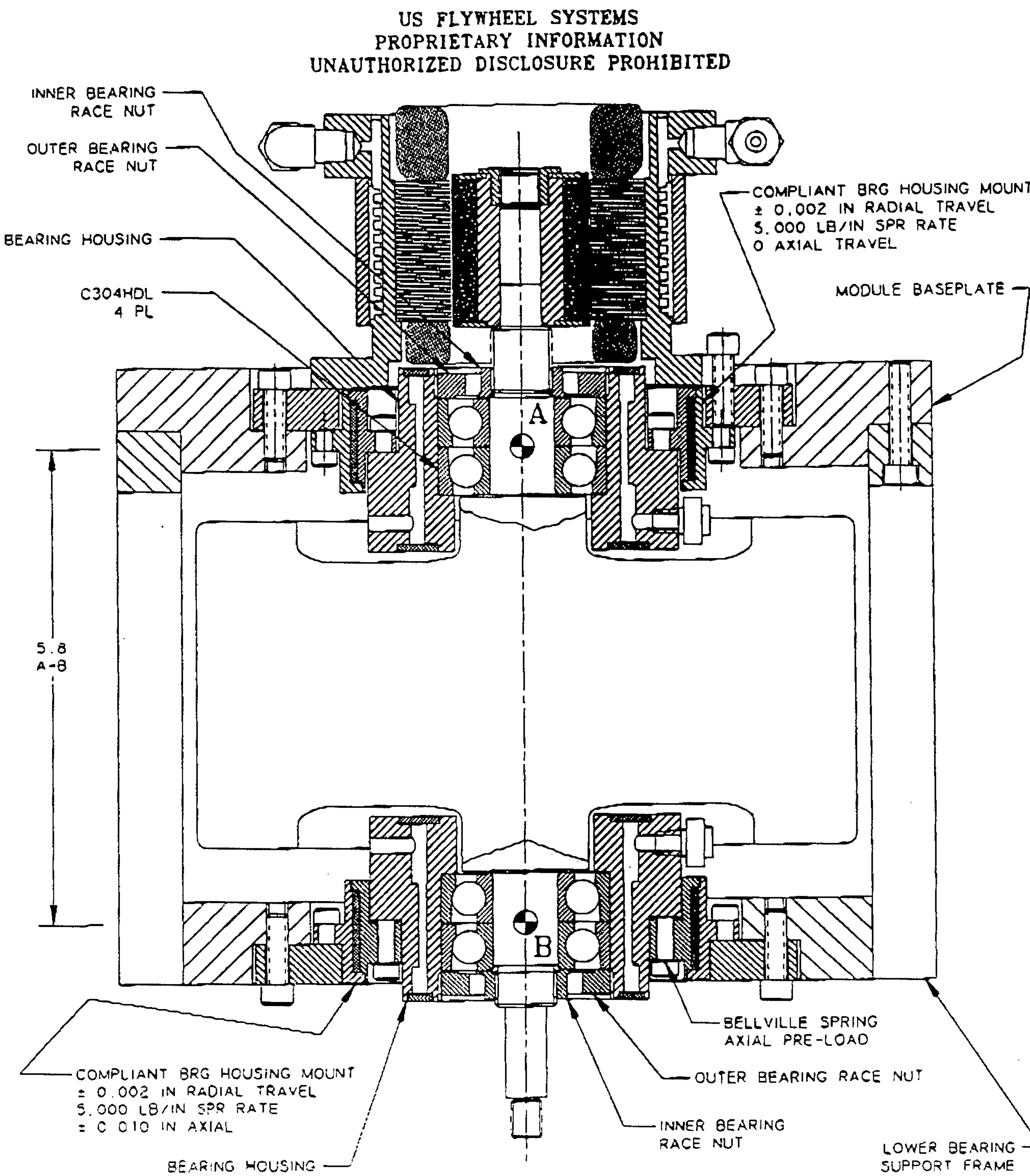
FLYWHEEL SHOCK TESTING

Project Manager: US Flywheel Systems, Inc.
CS-AR97-05

Jack Bitterly of U.S. Flywheel Systems (USFS) provided a report on the status of this program to Dr. Robert Rosenfeld, Ryan Gallagher and Danny Jordan of DARPA during the program review held at CALSTART, April 1, 1998.

USFS has finished a second-generation advanced unit in which the vertical spin axis has been completely redesigned. The new system was fabricated and has been tested in excess of its 42,000 rpm design speed. USFS made this improvement without delaying the project or increasing the cost to DARPA. USFS has begun testing on a new magnetic bearing satellite energy storage system in its test pit. There were no significant deviations to the planned schedule. Next quarter, USFS will finalize the target shock and vibration testing envelope for both systems and visit a number of major users. USFS also plans to visit Aberdeen Proving Grounds to prepare for future tests.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Test Data Collection	45,000	45,000			12/31/97	45,000	45,000
2	Establish test parameters and profile	33,000	52,000			12/31/97	33,000	52,000
3	Report on designs/fabrication	5,000	10,000					
4	Shock testing. Design/fab mounting system	235,000	255,000			12/31/97	157,530	17,243
5	Prepare for testing	5,000	10,000					
6	Testing at Aberdeen. Final Report	82,000	78,000					
		450,000	450,000				235,530	114,243



US FLYWHEEL SYSTEMS
PROPRIETARY INFORMATION
UNAUTHORIZED DISCLOSURE PROHIBITED
INNER BEARING RACE NUT
OUTER BEARING RACE NUT
BEARING HOUSING
C304HDL 4 PL
COMPLIANT BRG HOUSING MOUNT
± 0.002 IN RADIAL TRAVEL
5.000 LB/IN SPR RATE
0 AXIAL TRAVEL
MODULE BASEPLATE
A
5.8
A-B
B
BELLVILLE SPRING
AXIAL PRE-LOAD
COMPLIANT BRG HOUSING MOUNT
± 0.002 IN RADIAL TRAVEL
5.000 LB/IN SPR RATE
± 0.010 IN AXIAL
OUTER BEARING RACE NUT
INNER BEARING RACE NUT
BEARING HOUSING
LOWER BEARING SUPPORT FRAME

Figure 1

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COMPACT, RUGGED, LOW COST CIRCUIT BREAKERS FOR ELECTRIC AND HYBRID ELECTRIC VEHICLES

Project Manager: ***Potomac Electric Power Company w/Coriolis Corporation***
CS-AR95-03

During the quarter, the Potomac Electric Power Company (PEPCO) undertook an evaluation of its technology development programs, and, as a result, did not launch any new programs. The review delayed the start of this project. However, PEPCO's Brad Johnson indicates that PEPCO still plans to move forward with this project and provide the required cost share. PEPCO had intended to work with EPRI on this project but found that it was too difficult to do so. PEPCO has the scope of work and contract from CALSTART and indicates it should sign the agreement during the next quarter. Coriolis is still ready to commence work on the project as soon as funding commitments are in place.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Final draft of electrical test station design	5,307	5,400	1	TBD			
2	Select mechanical design team. Complete design.	33,708	34,292	2	TBD			
3	Design modifications to circuit breaker. Construct/debug test station. Fabricate circuit breaker components.	30,238	30,762	3	TBD			
4	Test guillotine circuit breakers.	19,217	20,171	4	TBD			
5	Final guillotine circuit breaker design.	11,530	9,375	5	TBD			
		100,000	100,000					

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ALTURDYNE ROTARY ENGINE APU TRANSIT BUS DEMONSTRATION

Project Manager: ***APS Systems***
CS-AR95-04

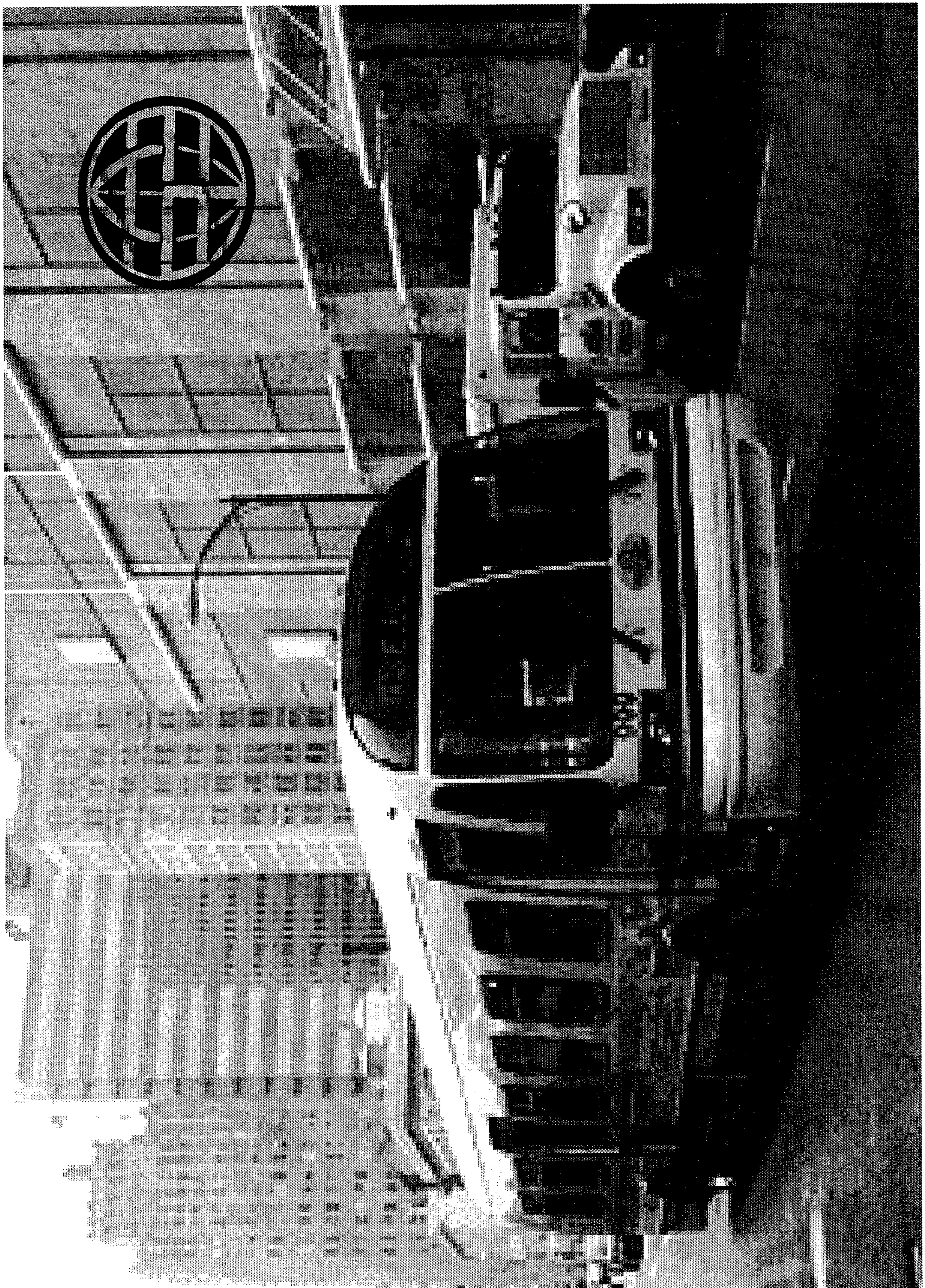
CALSTART coordinated with Alameda/Contra Costa (AC) Transit and APS Systems for a roll-out of the bus in early February at AC Transit's Emeryville facility. The press release that CALSTART issued announcing the rollout of the bus is included with this report. A copy of *CALSTART Connection* with a story on the bus is also attached as is the information sheet distributed by CALSTART at the rollout.

After extensive shakedown testing with AC Transit, the bus was placed into revenue service in mid-March, 1998. The bus has been in constant service on a number of different routes throughout AC Transit's service area.

APS continued to support the APU following delivery of the bus to AC Transit in the last quarter. AC Transit encountered problems with faulty sensors shutting the APU down but these were corrected quickly. AC Transit has reported to CALSTART that the bus is performing well and is being well received by its customers who are impressed with the low emissions, performance and low noise.

APS Systems is beginning to look at the potential of partnering with a bus manufacturer to commercialize the bus. CALSTART continues to monitor this project closely and will provide more data on APU performance when it becomes available. Initial numbers from AC Transit are indicating a fuel consumption of 2.67 gallons of propane per hour. If the bus were run in regular transit service at an average speed of 20 mph that would translate to 7.5 mile per gallon of propane (11 miles per diesel equivalent gallon). This compares favorably with the fuel economy of a conventional diesel bus of around 5 mpg. The bus will continue testing with AC Transit all through the next quarter.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Alturdyne bus demonstration	65,000		1				58,500
		65,000	**0**					**58,500**



The APS Systems 40-ft. Hybrid Transit Bus

Fact Sheet

Fuel Type: Propane/Electricity

Batteries
Type: Saft

Flooded Nickel Cadmium
Amount: 58
Voltage: 348 V
Weight: 3,000 lbs.
Battery Life: 5 years

Propane Fuel
Capacity: 52 gallons
Weight: 1,200 lbs.
Consumption: 2.8 gallons/hr.

General Bus Specifications
Dimensions
Length: 40'
Width: 98"
Height: 110"
Gross Vehicle Weight: 31,000 lbs
Curb Weight: 22,500 lbs.
Payload: 6,300 lbs
Passenger Capacity: 41 people

Bus Performance Specifications
Range
Single charge - Electric only: 45 miles
Hybrid mode: 210 miles

Maximum Speed
Level Ground/Full Capacity: 50 MPH
Speed on 2.5% Grade: 30 MPH
Speed on 12% Grade: 7 MPH

The 40' Hybrid Electric Transit Bus CALSTART, with its hybrid electric bus project team members, has developed an advanced 40' hybrid electric transit bus, a cleaner and more energy-efficient alternative to traditional buses. The bus is designed to have numerous advantages over conventional 40' buses, including lower emissions, greater operating efficiency, a low-floor for easier entrance and exit and a quieter ride.

The bus was designed and built by Oxnard, CA-based APS Systems which has been designing and building advanced battery-powered transit vehicles and components since 1991. The bus will be placed into service for six months with AC Transit followed by an additional six months in Orange County with the Orange County Transportation Authority (OCTA).

A Unique Collaborative Development

In 1994, CALSTART, a non-profit organization promoting the advanced transportation industry, initiated a project to design, build and demonstrate a full-size hybrid electric transit bus. The end result was a coordinated team effort, managed by CALSTART, involving funds from the Federal Transit Administration (FTA), the California Energy Commission (CEC), the Defense Advanced Research Projects Agency (DARPA), and Alameda/Contra Costa (AC) Transit. The project also received in-kind support from the Orange County Transportation Authority (OCTA), Southern California Edison (SCE), Pacific Gas and Electric (PG&E) and APS Systems.

CALSTART

Tracking a New Industry™

Technical Features

- Stainless steel provides the chassis strength.
- Aerospace composites are used in the body because of their rigidity and light weight.
- Nickel cadmium batteries, providing greater range and longer cycle life than conventional lead acid batteries.
- Twin 68 kilowatt (kW) Rexroth electric motors, which draw energy directly from the battery pack, provide the motive power for the wheels.
- 60 kW charger and a propane-fueled auxiliary power unit (APU) built by Alturdyne, Inc. of San Diego, CA.
- APU provides a constant power output of 40 kW that constantly recharges the battery pack.
- Regenerative braking which recovers energy, resulting in improved range and reduced wear on the conventional brake pads.

Bus Operating Modes

The bus will be able to operate in three modes:

- zero emission, when operating on the battery pack alone
- electric plus low-power auxiliary power unit, when the battery pack is capable of handling the traction demands but added energy is needed for accessories such as air conditioning, heating, lights, or windshield wipers
- electric plus high-power auxiliary power unit, when the battery pack requires augmentation to provide adequate energy for completion of the duty cycle. This will ensure that the bus will be able to perform under all conditions without sacrifice of speed, range, safety, or passenger comfort.

40kw Alturdyne APU provides the electrical power to the battery pack for extended range.

CALSTART 40' Transit Bus with Range Extender Program History

In 1994, CALSTART, a non-profit organization promoting the advanced transportation industry, initiated a project to design and build a full-size hybrid electric transit bus. The end result was a coordinated effort, led by CALSTART, involving the Federal Transit Administration (FTA), the California Energy Commission (CEC), the Defense Advance Research Projects Agency (DARPA) and AC Transit. The project also received in-kind support from the Orange County Transit Authority (OCTA), Southern California Edison (SCE), Pacific Gas and Electric (PG&E) and APS Systems.

The bus will be placed into service for six months with AC Transit followed by an additional six months in Orange County. The bus was built by Oxnard, CA based APS Systems which has been designing and building advanced battery powered transit vehicles and components since 1991. The bus is designed to have numerous advantages over conventional 40-buses, including lower emissions, greater operating efficiency, a low-floor for easier entrance and exit and a quieter ride.

CALSTART

FOR RELEASE
February 12, 1998

CONTACT: Bill Van Amburg, CALSTART
(818) 565-5606

BAY AREA SERVICE BEGINS FOR NATION'S MOST ADVANCED ELECTRIC TRANSIT BUS

NEW GENERATION OF CLEANER, QUIETER, MORE-EFFICIENT HYBRID BUS BEING TESTED BY CALSTART-LED PARTNERSHIP OF PRIVATE COMPANIES AND PUBLIC AGENCIES

Emeryville, Calif. – A revolutionary and environmentally-friendly transit bus – one of the most advanced in the nation – begins testing today as a part of Northern California's Alameda/Contra Costa (AC) Transit fleet. Utilizing a combination of battery and propane power, the hybrid-electric bus demonstrates the newest heavy-duty technologies for greatly improving fuel-economy, lowering emissions, and reducing noise.

A project of CALSTART, the advanced transportation organization, the new bus is an important step in the push for cleaner air, higher efficiency, and high-tech jobs. In addition to fewer emissions, the new bus incorporates a series of other features that transit users will appreciate, including a flat floor for easy ingress, and quieter, smoother operation.

"The recently signed global warming accords at Kyoto really bring home the need and potential for this type of technology," said Michael J. Gage, president & CEO of CALSTART. "Increasingly efficient, clean transportation solutions such as this bus – ready for deployment today – clearly show the technical realities this growing industry can deliver."

Produced by CALSTART participating company APS Systems of Oxnard, California, the bus utilizes a new generation hybrid-electric driveline that greatly reduces pollution, vibration, and noise. Two electric motors, producing the equivalent of approximately 180 horsepower, drive the buses' wheels under all conditions. An advanced, nickel-cadmium battery pack provides power for the electric motors, and can be charged on demand by a propane-fueled, rotary-engine generator.

The hybrid combination allows the bus to operate in three separate modes, each guaranteeing maximum energy efficiency and minimal environmental impact. When

(more)

operating on batteries alone, the bus produces zero emissions and can travel up to 45 miles. If traction requirements can be met by the battery but accessories are needed (air conditioning, lights, wipers, etc.), the generator operates in a low-power mode. A high-power mode is also available, which further charges the batteries and is capable of extending the vehicle's duty cycle to a total of 230 miles, depending on terrain. Running full-time, the generator consumes only 2.8 gallons of propane per hour. A proof-of-concept prototype, the vehicle could become the first of a new generation of city buses.

The new bus will be in service for 6 months over many of AC Transit's routes to allow passengers, drivers, mechanics and others to evaluate its performance and advantages. Afterwards, it will pass to the Orange County Transportation Authority (OCTA) for an additional 6-month trial.

With several private and public partners, CALSTART initiated this novel project to design, build, and demonstrate a full-sized hybrid-electric transit bus. Alturdyne produced the vehicle's auxiliary power unit, and worked closely with APS Systems. Funding for the project came from AC Transit, the Federal Transit Administration (FTA), the Defense Advanced Research Projects Agency (DARPA), the Bay Area Air Quality Management District (BAAQMD), the California Energy Commission, the Orange County Transportation Authority (OCTA), Southern California Edison (SCE) and Pacific Gas and Electric (PG&E).

CALSTART is a non-profit advanced transportation technologies organization working with more than 200 industry and public partners worldwide. It develops technology demonstration programs, provides industry analysis and information and helps fleets more quickly introduce electric vehicles, hybrid-electric vehicles, natural gas vehicles, as well as Intelligent Transportation Systems (ITS). For more information on CALSTART and advanced transportation, please visit the consortium's web site at **www.calstart.org**.

Promoting Advanced Transportation Technologies Today: www.calstart.org

THE CALSTART Connection™

Volume 6, Issue 1 1st Quarter 1998

Toyota Receives 1997 Blue Sky Award

Toyota Motor Corporation, led by its Prius hybrid-electric car, has won the 1997 Blue Sky Award. The award is given to recognize outstanding marketplace contributions to advanced, sustainable transportation that cleans the air, improves energy efficiency and helps reduce greenhouse emissions.

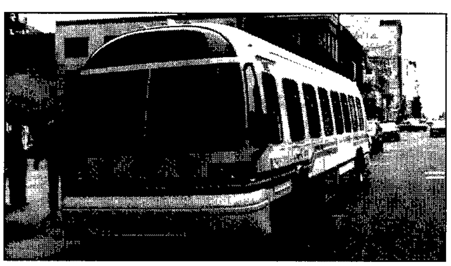
Toyota was recognized in particular for the market launch of its innovative, clean and fuel-efficient Prius hybrid-electric car, which it is now selling in Japan. This, combined with its commitments to

CALSTART president and CEO Michael Gage presents Blue Sky Award to Dave Illingworth, senior vice president and general manager of the Toyota Division of Toyota Motor Sales U.S.A.

See BLUE SKY AWARD, page 7

CALSTART Launches The Nation's Most Advanced Hybrid Electric Transit Bus

Bus Enters 12-Month Test with AC Transit and OCTA



Hybrid-electric bus consumes only 4.2 gallons of propane per hour for a range of 230 miles.

A revolutionary and environmentally-friendly transit bus–one of the most advanced in the nation–is now in service as a part of Northern California's Alameda/Contra Costa (AC) Transit fleet. Utilizing a combination of battery and propane power, the hybrid bus demonstrates the newest heavy-duty technologies for greatly improving fuel-economy, lowering emissions, and reducing noise.

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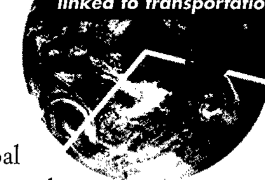
CALSTART forms new funding opportunities, see page 3

See HYBRID ELECTRIC BUS, page 7

SPECIAL REPORT

Agreement in Kyoto: The Impact on Transportation

33% of greenhouse gas emissions causing global warming are linked to transportation



The Kyoto blueprint may eventually be seen as a landmark first-step in the fight against global warming. It is also another key factor in the increasing pressures changing transportation, fuels, and technologies.

Signed by many nations hoping to reduce alterations of the earth's natural "greenhouse effect" (GHE), it could provide a path toward halting documented global change. The earth's average temperature has already risen by approximately 1 degree Fahrenheit over the last century–and 33% of greenhouse gas emissions causing global warming are linked to transportation.

See GLOBAL WARMING, page 4

In This Issue:

New CALSTART Participants

CALSTART welcomes 13 new members of the advanced transportation industry:

- **Ang'elil Graham Architecture**
  Designs photovoltaic public infrastructure and recharging stations for electric vehicles.
  ✆ *Contact: Sarah Graham, (213) 871-1450*

- **Bowles Langley Technology**
  Plans to produce a device to test drivers for states of alertness.
  ✆ *Contact: Henry Bowles (510) 864-3111*

- **The City of Alameda**
  Supports the development of an EV Model City Program, and is an applicant for a Clean Cities Designation.
  ✆ *Contact: Bruce Knopf (510) 747-4700*

- **Extengine, LLC**
  Develops electric vehicle propulsion systems and manufactures lead-acid battery additives.
  ✆ *Contact: Phillip K. Roberts (562) 983-8180*

- **FEV Engine Technology**
  Develops and tests internal combustion engines, and provides engine engineering consulting.
  ✆ *Contact: Gary W. Rogers (248) 373-6000*

- **General Atomics**
  Develops unmanned aircraft, ground control stations, ground data terminals, and heavy fuel engines.
  ✆ *Contact: Jennifer Petersen (619) 455-2667*

- **Ginter VAST Corporation**
  Develops low pollution combustors for turbine-powered vehicle applications.
  ✆ *Contact: Suzi McCraw (310) 557-1511*

- **It's Electric!, Inc.**
  Specializes in electric vehicles, and will open a retail outlet early in 1998.
  ✆ *Contact: Michael S. Wyman (510) 525-0503*

- **Pinnacle Mining N.L.**
  Plans to utilize its exclusive rights to Vanadium Redox battery technology in electric vehicle applications.
  ✆ *Contact: Dr. Malcolm T. Jacques +61 3 9824 8166*

- **Proe Power Systems**
  Develops alternatives to gas turbines and diesel engines based on the Ericsson cycle.
  ✆ *Contact: Richard Proeschel (800) 308-2651*

- **Rexxar Corporation**
  Develops centrifugal automatic transmissions.
  ✆ *Contact: Joel Nevels (510) 757-2198*

- **VOLTEK, Inc.**
  Develops the "Fuel Pak" metal/air fuel cell and its A-2 electric vehicle.
  ✆ *Contact: Gordon R. Stone (618) 277-5130*

- **Waste Energy Integrated Systems, L.L.C.**
  Researches the production of ethanol from biomass waste and develops a reactor for ethanol production.
  ✆ *Contact: Charles K. Lombard (650) 858-2114*

Want to join the team that's changing transportation? CALSTART participant services include regular information, partnering and access to funding opportunities. To become a CALSTART participant, call (818) 565-5600.

Advanced Transportation Business Training!

CALSTART, in partnership with California's Employment Training Panel (ETP), is offering a variety of training programs and workshops this quarter. Participation is free of charge to most employees and business owners.

Business owners and managers can earn an Entrepreneurial Management Certificate (EMC) by attending classes one night a week for six weeks. One topic will be covered each evening, including: marketing management; engineering management; project management; cash flow management; manufacturing quality; and the high-performance workplace.

In addition to the certificate program, CALSTART will offer a variety of training workshops. These workshops typically involve 15 to 20 hours of classroom training, and will cover 28 individual topics including business, communications, manufacturing, design, development, project management, and finance.

For a full list of the exciting workshops available, or for more information on dates and locations, please contact Steve Duscha at (916) 442-4854.

CALSTART Forms New Partnership With Departments of Transportation and Energy

Secretaries Make Joint Presentation in Washington D.C.

On February 5, 1998, CALSTART received major support and funding from a new nationwide program announced by the U.S. Departments of Transportation and Energy. Six other advanced transportation technologies consortia (ATTC) were also involved.

The new ATTC program will take $20 million–$10 million each from the Departments of Transportation and Energy–and match that with an equal amount from private companies working with the consortia on selected programs. This cooperative model, supporting cost-effective, "bottom-up" innovation, was actually based on CALSTART, the oldest and largest of the advanced transportation technologies consortia.

Secretary of Energy Federico Pena and Secretary of Transportation Rodney Slater made the announcement at a rainy-day event which showcased a number of CALSTART participants. Also present were EPA administrator Carol Browner, Under Secretary of Defense Dr. Jacques Gensler, and Director of the White House Office of Science and Technology, Dr. John Gibbons.

"This new partnership will help commercialize more efficient vehicle systems that reduce pollution," said Secretary Pena. "American consumers and businesses can look forward to a cleaner environment because of the transfer of these energy-efficient military technologies."

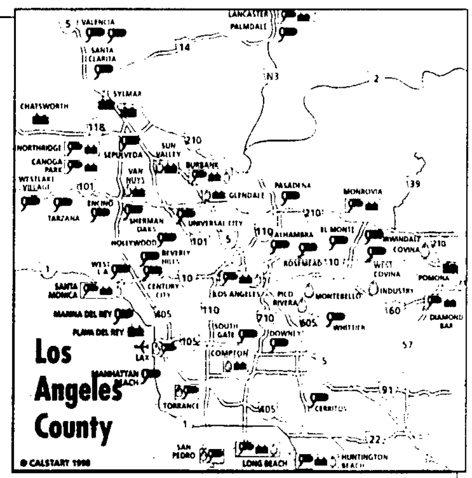
Nationwide, more than 400 technology companies are part of the ATTC network. Vehicle and component projects receiving emphasis under the new ATTC program will include electric, hybrid-electric, natural gas, hydrogen and other technologies, including electronic control and communication systems.

Advanced Transportation Industry Web Site

WEB TALK

www.calstart.org

33% Growth in LA County Charging Sites at www.cleancarmaps.com!



www.cleancarmaps.com

Driving an electric vehicle has become even easier in Southern California, where many new charging sites have recently been added. Los Angeles County and surrounding areas are now home to scores of inductive charge sites at supermarkets, hotels, banks, malls and hospitals.

CALSTART has helped keep pace with the rapid pace of these new installations by completing a major update of its Clean Car Maps site on the Internet at **www.cleancarmaps.com**. There are now over 45 additional charge sites included in CALSTART's easy-to-use, graphical mapping system. It has been simultaneously expanded to cover several subregions in L.A. County, including Santa Monica, West Los Angeles, Downtown, Long Beach and Torrance.

New locations are also searchable by city at **www.calstart.org/services/caevlisting.html**.

CALSTART will update other counties throughout California as they become available, and will soon be cataloging recharging and refueling sites nationwide. Stay tuned. If you know of a recharge site in California and would like it included in our mapping system, please contact Gina Lupo or Dave Sotero at (818) 565-5600.

CALSTART Board Elects New Chairman and Secretary

David Abel has been elected Chairman of the Board at CALSTART. An investor and board member at SuperShuttle, Abel recently took the reigns from long-time CALSTART Chairman Michael Peevey. Vincent Fiore of the Gas Research Institute (GRI) has also been elected Board Secretary.

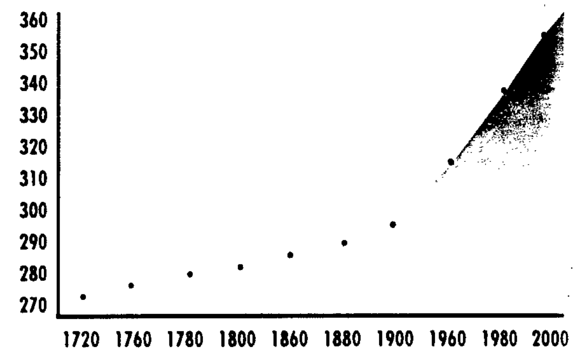
Global Warming–The Impact on Transportation

continued from page 1

The Need for Action

Given these facts, it is easy to see the importance of Kyoto to the transportation industry. If the treaty is to be observed, large cuts in GHG emissions will be required, particularly from the United States. Already 7.4% above 1990 levels at the end of 1996, U.S. emissions are increasing at an annual rate of over 3%. The Clinton administration's plan to begin decreasing U.S. emissions calls for a broad range of tax incentives and government-funded R&D to spur investment in energy efficiency. Regardless of the path chosen, the reductions required will likely involve the following: fossil fuel consumption (the primary source of carbon dioxide [CO_2] emissions), will need to decrease substantially and in absolute terms; U.S. energy prices, which have declined 50% in real terms since 1980, will very likely rise; increased private and public sector funding will be channeled into the development and commercialization of energy sources with smaller GHG emissions; and market opportunities will increase dramatically for high-efficiency, low GHG emitting technologies.

Historical View of Atmospheric CO2 Levels



Source: Oak Ridge National Laboratory

Greenhouse Gases and Transportation

GAS	TYPICAL SOURCES	ANNUAL RATE OF CHANGE
H_2O	hydrological cycle, fuel combustion	variable
CO_2	combustion of fossil fuels and biomass, animal respiration	+.5%
CH_4	organic decay, waste treatment, rice paddy agriculture, biomass burning, livestock production, natural gas transport, venting during coal and gas production	+1%
O_3	formed through interaction of H_2O, NO_x, hydrocarbons and sunlight	N/A
N_2O	tropics, fossil fuel combustion, manufacture and use of chemical fertilizers	+.2-.3%
CFC 11/12	production and use of air cooling devices	+.5%

Source: Energy Information Administration

Surface temperature is regulated by atmospheric gases in a series of sensitive relationships; they absorb, scatter, and trap heat emanating from the surface. Changes in temperature can potentially cause rising sea levels, shifting climactic zones, increased weather and rainfall disparities, and drive increasingly extreme weather phenomena. Only a few of the gases in the atmosphere have heat-trapping, global-warming potential; they include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), and fluorocarbons (CFC11/12). Although atmospheric increases in many of these gases are popularly attributed to industrial sources like power plants and factories, it is important to note that transportation currently accounts for about 33% of all greenhouse gas emissions from the developed world. Approximately 50% of the world's oil consumption can be attributed to transportation as well, and if trends continue, it is projected to quickly become the most prolific sector for emissions.

Battling the Trends

In any case there can be little doubt that Kyoto has mobilized public opinion in favor of reducing GHG emissions, and that people will continue to press for cleaner transportation options. Additionally, many trends within the industry reinforce an immediate need for action, and the urgency of new solutions. For example, people are not only driving more cars, they are driving more. Vehicle miles traveled are increasing worldwide, and have grown 69% in the U.S. alone since 1969. Total vehicles in operation worldwide will total 1 billion in 2010 if current growth trends continue. The average car sold is also growing markedly less efficient. Light trucks, pickups, and sport utility vehicles account for nearly half of all new car

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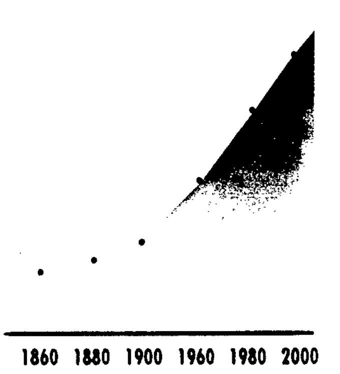
Atmospheric CO2 Levels



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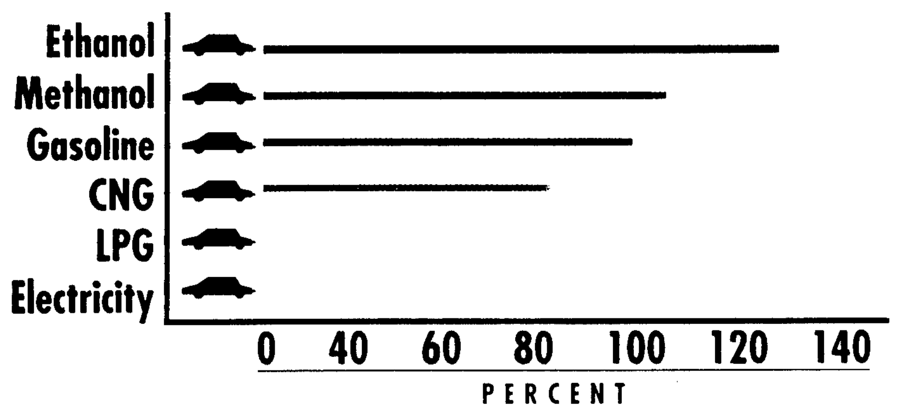
Greenhouse Gas Emissions of Alternative Fuels Relative to Gasoline



Source: American Institute of Chemical Engineers

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e Trends

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> ***...trends in the industry are creating a market opening, much like any other. Those who are in the best position to capitalize on the necessary and inevitable changes will profit.***

Opportunities Ahead

Opposition to the Kyoto accord frequently states that the price to pay for reducing GHGs is too great. It is claimed that only the complying country's economy will be penalized, while those with increasing trade and few pollution controls will be unfairly advantaged. These arguments choose not to acknowledge the increased efficiency and profitability historically linked to clean-air technologies. Public awareness from conferences like Kyoto and trends in the industry itself are creating a market opening, much like any other. Those who are in the best position to capitalize on the necessary and inevitable changes will profit. Tremendous opportunities lie between what transportation is now, and what it must become.

The Complications of Ratification

The Kyoto agreement now faces ratification on each of the signatory countries' home soil. Pledges for greenhouse gas (GHG) reduction are based on levels of the specified gases in 1990. The United States is committed to reducing emissions of GHGs to 7% below 1990 target levels by 2008-2012, while European and other developed nations must reduce emissions below the target by 8% and 6% respectively. China and India, the two most populous countries, are siding with a number of developing nations in choosing not to sign the agreement. They argue that, as developed nations have caused most of the damage, developing nations should not be expected to pay for damage they did not do. The assertion is in part correct, but adopts a particularly short-term view. Assuming current patterns of growth are sustained, emissions from developing nations (particularly China and India) are expected to overtake those of the developed world early in the next century.

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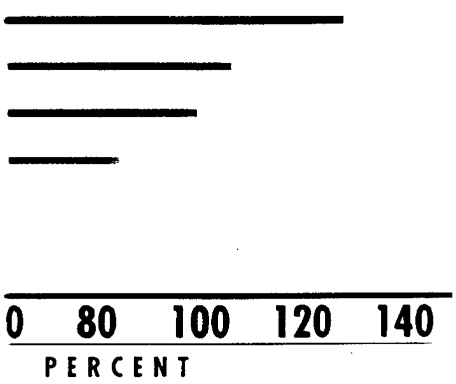

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Commentary on Kyoto

continued from page 8

Clearly, Toyota is striving for market share and believes this subsidized price will help them gain volume and knowledge; which will lead to lower costs and higher profit. These actions place Toyota squarely in front as the technology leaders and "environmental auto makers."

CALSTART, and its network of roughly 200 advanced transportation companies, believe there is competitive advantage in this leadership. Because if Porter is right, then both Toyota and Honda are poised to develop strategies that diminish global greenhouse gases faster than other automakers. Then when the rest of the world, including U.S. consumers, demand vehicles that meet the needs of the planet in addition to their personal needs, Toyota and Honda will have an early competitive advantage over the Big Three. Based on current posturing and positioning, consumers may already assume that Toyota and Honda are more technologically capable than the Big Three, and that they care more about the environment. That suggests a strong competitive advantage to Toyota and Honda in terms of brand identity.

If both Japan and the European Union comply with the accords (which apparently they are embracing), their automakers will gain clear competitive advantage over the Big Three–and become the automakers of choice in the developing world, as well.

Can we afford that?

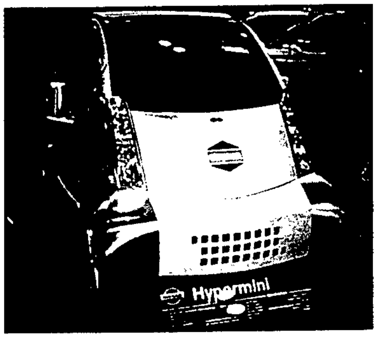
Based on Porter's research and just a smidgen of common sense, every business operation today should assume that global warming is real, and that the current accords don't go far enough. They should assume that energy efficiency and environmental friendliness are increasingly important factors in the global marketplace. Only then will they ensure that they aggressively pursue a path that helps them remain competitive in the global marketplace of the 21st century.

*Content provided by **Zak Cook**, CALSTART Policy Analyst.*

3

International Commitment Shines at EVS-14

A flurry of strategic partnerships and impressive new-product introductions set the tone for an exciting week at EVS-14. Activity during the show was highlighted by an incredible level of international interest and investment, as



Nissan's Hypermini was widely admired for its styling and execution. Future production is a possibility.

well as a growing sense of competition amongst the exhibitors. Pushed ahead by the speed, momentum, and importance of its key players, the gathering significantly raised the bar on expectations for the future.

Toyota Stirs Competition for Green Status Among Manufacturers

Aggressively moving to "brand" themselves as the most environmentally friendly auto manufacturer, Toyota put increasing image and product pressure on their competition by introducing both its Prius Hybrid and e-com commuter to the United States at EVS-14, as well as exhibiting the RAV-4 EV.

The 66 MPG Prius was driven by many at the Ride and Drive, and never failed to impress with its smooth performance and technical wizardry. Marketed only in Japan, it may be sold in the U.S. by the year 2000. Orders for the domestic market have risen to 3500 units, surpassed all expectations, and caused Toyota to double its production capabilities from 1000 to 2000 units per month.

The diminutive e-com also drew crowds, many complimenting its novel and futuristic lines. Intended for shorter trips and powered by 24 nickel-metal hydride batteries, it was said to have a range of about 60 miles. Tiny cars like the e-com should make EV production more profitable for manufacturers, as the proportionately smaller battery packs required would serve to hold down costs.

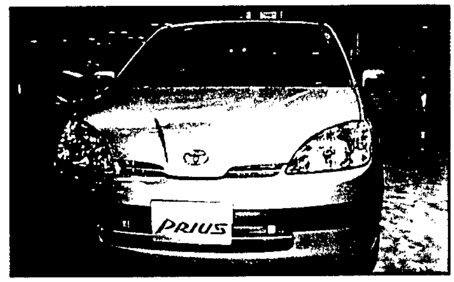
Future Nissans Debut As Well

Just behind Toyota, Nissan chose the show to debut its lithium-ion powered Altra EV station wagon. Utilizing the same inductive charging system as GM's EV1, the Altra EV was said to have a 120-mile range. Plans were revealed to deliver 30 demonstration units to fleet operators in 1998, followed by 90 more units in 1999. Delivery to retail companies was said to begin in the year 2000. The company also showed its Hypermini, a commuter-sized prototype. Although no plans for production were discussed, the car was designed with production considerations and all safety standards in mind.

Important Agreements Signed

A number of important partnerships were announced and expanded during the show. Most notably, Ford Motor Company announced a partnership with Ballard Power Systems and Daimler-Benz valued at $420 million. The agreement to develop, sell, and use fuel-cell power systems in electric vehicles marked yet another major commitment to the future of hydrogen technology. When finalized, the resulting alliance was to show Daimler-Benz and Ford owning 20% and 15% of Ballard respectively. A second entity, DBB Fuel Cell Engines GmbH, would be majority-owned by Daimler-Benz with Ballard holding 26% and Ford 23% of the company. Ford's major interest was to be in an unnamed drivetrain group, with Ballard and Daimler-Benz each holding 19%.

A number of energy companies also partnered in important agreements.



Rich in technology and innovation, sales of the remarkable Prius have been virtually double Toyota's expectations.

Bombardier unveiled a partnership with Edison EV for the test-marketing of its Neighborhood Electric Vehicle (NEV), and AeroVironment announced an agreement with the Southern Co. to distribute its PosiCharge EV fast-charging station.

Increasing Promise from Detroit

The Detroit Auto Show followed quickly on the heels of EVS-14, and reiterated the competition developing between automakers. Ford announced that a road-going hybrid version of its P2000 show car would be ready in

Edison EV will help market Bombardier's NV to over five million people living in planned communities, a number that could double in a decade.

1998, and GM declared that stretched versions of its EV1 in hybrid and fuel cell form would be in production by 2001 and 2004 respectively.

These planned product launches by the largest manufacturers show that industry-wide marketing and development strategies are rapidly maturing. The next 12 months should see competition increasing!

Blue Sky Award

continued from page 1

three other clean fuel vehicles and markets–the Coaster hybrid electric bus, the RAV4-EV electric vehicle and the announcement of the e-com electric commuter car–led to its selection as the top award winner for 1997.

"Toyota's actions are currently setting the trend globally in clean, efficient vehicles," said Michael J. Gage, CALSTART president & CEO. "Their efforts, highlighted by their innovative hybrid systems, are redefining passenger transportation and efficiency, which are crucial for both air pollution and global warming. We're proud to honor these solid market commitments with our second annual award."

"We are honored to accept this prestigious award from CALSTART and its participants," said Dave Illingworth, senior vice president and general manager of the Toyota Division of Toyota Motor Sales U.S.A., Inc. "We have received much recognition lately for the innovation in our vehicles, but this award recognizes their value to the environment as well." Illingworth also mentioned that the company would sell a hybrid-powered vehicle in the U.S. before the end of the century.

Blue Sky Merit Award Winners

Toyota received the top Blue Sky Award for 1997, but there were also four Merit Awards, honoring significant companies, people and organizations:

Ballard Power Systems, of Vancouver, Canada, won for its continuing technology innovation and push to the marketplace with fuel cell power systems. Ballard in 1997 formed a partnership with Daimler-Benz of Germany to develop, build and market fuel cells for the automotive and other markets by the turn of the century, accelerating the fuel cell's market use.

James Worden, founder and chief executive officer of Massachusetts-based Solectria Corporation, a leading-edge electric vehicle technology developer and vehicle maker who continues to push the limits of the marketplace uses of clean vehicles. This year Worden again changed the perception of electric vehicle uses by driving non-stop at freeway speeds from Boston to New York in his prototype "Sunrise" electric car.

SunLine Transit of Thousand Palms, California, a transit industry leader for its commitment to a 100 percent natural gas-powered bus fleet, and its continuing leadership in helping install natural gas refueling infrastructure, training mechanics in natural gas systems and testing and using new, clean technologies.

Sacramento Regional Transit, Sacramento, California, is also honored as a transit leader for its operation of more than 65% of its fleet of buses on natural gas, and its development of some of the best fuel cost and maintenance data on natural gas-powered vehicles. In 1997 Sacramento RT figures showed it was saving more than $1 million each year in reduced fuel and maintenance costs.

The Blue Sky Award is specifically designed to recognize not just leadership and innovation in technology for clean transportation, but a significant commitment to its use. Last year, CALSTART presented its first award to General Motors for the automaker's EV1 electric vehicle launch in the marketplace.

Nominations for next year's award are open to all via fax, mail and CALSTART's Internet Web site at **www.calstart.org/bluesky**.

Hybrid Electric Bus

continued from page 1

motors, and can be charged on demand by a propane-fueled, rotary-engine generator. Alturdyne produced the vehicle's auxiliary power unit, and worked closely with APS Systems.

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A Business Case for Embracing the Kyoto Accords

by Michael J. Gage, President & CEO, CALSTART

While some segments of the business community vigorously attacked adoption of the Kyoto accords, there exists a very strong business case for U.S. businesses to behave as if the accords were ratified and will only get stronger in the future.

Clearly the changes required may be viewed as disruptive to some. Yet one key to competitiveness requires interpreting approaching trends and effectively acting on that knowledge before one's competitors. The Kyoto accords offer competitive advantages to U.S. businesses which embrace them and will soundly punish those businesses that ignore them.

Michael Porter, Harvard scholar, economist, and highly regarded business strategist, writes frequently of competitive advantage for businesses and even nations. Porter has said that when demanding consumers or "tough government regulations anticipate standards that will spread internationally they give a nation's companies a head start in developing products and services that will be valuable elsewhere". In California the regulatory focus on cleaning the air with electric and clean fuel vehicles has clearly helped give some U.S. companies a head start–we've seen this in advanced transportation. But what will happen now if our businesses continue to resist these changes?

Does anyone really doubt that the global warming debate will soon dissipate? And given the dramatic, continuing increase in CO_2 in our atmosphere, do we really believe we won't need to address this build-up some time soon? Will America's companies cede the leadership in critically needed technologies to other countries that are more responsive to this global issue?

> ***"Energy efficiency and environmental friendliness are increasingly important factors in the global marketplace."***

A case in point is the automobile industry. While the "Big Three" promptly and predictably attacked the accords, Toyota promptly acknowledged that global warming was a problem, that they were part of the problem, and therefore they need to be a part of the solution. Honda also announced that they could live with the binding Kyoto Accords and they believed that developed countries should lead the way.

Toyota's actions match its words. While not the first to bring electric vehicles to market, their RAV-4 electric gets a driving range of 125 miles by using advanced (nickel metal hydride) batteries. They are also the first auto maker to target four different clean vehicle market segments, including the Coaster hybrid electric bus, their two-passenger electric e-com commuter car and their Prius hybrid electric four-passenger car, in addition to their electric RAV-4.

Toyota is now producing the Prius: 1000 per month for a purchase price of approximately $17,000 in Japan. The Prius and the Coaster bus, both in production, cut $C0_2$ gasses by 50%, in addition to reducing other pollutants by 90%, or more. The RAV 4 electric and the e-com commuter car cut global greenhouse gasses and other pollutants by more than 90%.

The true costs of the Prius are believed to be about double the current sales price.

See COMMENTARY ON KYOTO, page 5

THE CALSTART Connection

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The CALSTART Connection is always looking for more information. Readers are encouraged to send industry-related information for possible publication.

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ADVANCED HYBRID RECONNAISSANCE VEHICLES

Project Managers: ***AeroVironment and Rod Millen Special Vehicles (RMSV)***
CS-AR95-06A and B

Doug Stuedler and Eric Anderfaas of RMSV along with John McGuiness of AeroVironment represented their JTEV oriented military projects at the April 1, 1998 meeting arranged by CALSTART for Dr. Robert Rosenfeld of DARPA. Slides from the presentation are included in the Appendix.

The Naval Surface Warfare Center at Caderock issued a stop work order on this project in January 1998. As reported last quarter, Caderock is revising the scope of work for this project. CALSTART will continue to work with AeroVironment, Rod Millen Special Vehicles (RMSV) and Caderock to document the proposed changes in the scope of work. CALSTART will provide the proposed changes to DARPA for approval and expects to do so during the next quarter.

Prior to the stop work order, Rod Millen Special Vehicles nearly completed the detail design and fabrication of the suspension control system. RMSV indicates that this task is 97 percent complete. Under the contemplated changes to the scope of work, the suspension control system would be installed on a HMMWV rather than the Joint Tactical Electric Vehicle.

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*Project Managers: **AeroVironment and Rod Millen Special Vehicles***
CS-AR95-06A and B

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
	RMSV CS-AR95-06A							
1	Initiate work	75,000		1	4/1/96	4/3/96		75,000
2	Suspension/ Differential Dev	60,287		2	4/30/96	6/30/96		13,881
3	Design review	60,287		3	6/30/96	6/30/96		59,688
4	Suspension design	60,287		4	9/30/96	9/30/96		75,894
5	Project Report			5	12/31/96	1/2/97		60,071
6	Algorithm dev. Final report	60,288		6	2/28/97			31,615
	TOTAL	**316,149**	**0**					**316,149**
	AeroVironment							
	CS-AR95-06B							
1	Battery Mgmt Final rpt Inverter repkg final Low Acoustic Trans rpt. Peripherals rpt	309,974	53,972	1	9/31/96	9/31/96	53,972	309,974
2	DC-DC converter Design	215,495	37,520	2	12/31/96	12/31/96	37,520	215,490
3	Final Report	58,385	0	3	3/30/97			
	TOTAL	**583,854**	**91,492**				**91,492**	**525,464**

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PROPULSION SYSTEM FOR ADVANCED HYBRID RECONNAISSANCE VEHICLES

Project Manager: ***Rod Millen Special Vehicles and AeroVironment***
CS-AR96-09A and B

Work on battery pack development, investigation of different battery chemistries and two-speed transmission design continued to be on hold during the quarter. The unavailability of the Joint Tactical Electric Vehicle is the primary reason for the lack of progress. As a result, significant changes to the scope of work for this project are being contemplated. CALSTART will continue to work with AeroVironment, Rod Millen Special Vehicles and the Naval Surface Warfare Center at Caderock to detail any proposed changes to the scope of work. CALSTART will submit any proposed changes to DARPA for approval.

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PROPULSION SYSTEM FOR ADVANCED HYBRID RECONNAISSANCE VEHICLES

Project Manager: ***Rod Millen Special Vehicles and AeroVironment***
CS-AR96-09A and B

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
	AeroVironment CS-AR96-09A							
1	Initiate Work	69,282		0	12/31/96	12/31/96		**68,424**
2	Pack Mechanical Design Report	72,727		1	3/30/97			**13,113**
3	Battery Progress Report	92,727		2	6/30/97			**2,698**
4	2 Speed Trans report	74,066		3	9/30/97			
7	Final Report	50,910		4	12/31/97			
		359,712	**0**					**84,235**
	ROD MILLEN CS-AR96-09B							
1	Initiate work	38,614		1	9/30/96	9/30/96		38,614
2	Test platform support	38,615		2	12/31/96	12/31/96		8,361
3	ADC fabrication	38,615		3	3/30/97		6,000	42,962
4	ADC testing	38,615	10,000	4	6/30/97			18,505
5	ADC integrated JTEV	38,615	10,000	5	9/30/97			24,154
6	Algorithms refined	38,615	10,000	6	12/31/97			
7	Test complete/Final report	38,615	6,000	7	3/30/98			
		270,304	**36,000**				**6,000**	**132,596**

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JOINT TACTICAL ELECTRIC VEHICLE – FUEL EFFICIENCY TESTING PROCEDURE

Project Manager: ***AeroVironment***
CS-AR97-01

CALSTART and AeroVironment have not yet executed an agreement to commence this work. A number of changes to projects associated with the Joint Tactical Electric Vehicle are being discussed. Based on discussions with Jeff Bradel of the Naval Surface Warfare Center at Caderock, it appears that the proposed changes will not affect this project. If this is the case, CALSTART expects to execute an agreement with AeroVironment during the next quarter.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Modify JTEV to collect data for analysis	54,500			**TBD**			
2	Perform test plan/analyze data	36,500			**TBD**			
3	Final report	9,920			**TBD**			
		100,920	0					

JOINT TACTICAL ELECTRIC VEHICLE – HYBRID ALGORITHM REFINEMENT TESTING

*Project Manager: **AeroVironment***
CS-AR97-02

CALSTART and AeroVironment have not yet executed an agreement to commence this work. A number of changes to projects associated with the Joint Tactical Electric Vehicle (JTEV) are being discussed. It is likely that this project will not proceed, based on discussions with Jeff Bradel of the Naval Surface Warfare Center at Caderock. Caderock intends to request that funds from this project be redirected to other, new JTEV-related projects. CALSTART expects to submit the new proposed projects to DARPA for approval during the next quarter.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Modify JTEV to collect data for analysis	54,500			**TBD**			
2	Perform test plan/analyze data	36,500			**TBD**			
3	Final report	9,920			**TBD**			
		76,300						

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JOINT TACTICAL ELECTRIC VEHICLE ((JTEV) – PERIPHERALS DEVELOPMENT

Project Manager: ***Rod Millen Special Vehicles***
CS-AR97-03

CALSTART and Rod Millen Special Vehicles have not yet executed an agreement to commence this work. A number of changes to projects associated with the Joint Tactical Electric Vehicle (JTEV) are being discussed. It is likely that this project will not proceed, based on discussions with Jeff Bradel of the Naval Surface Warfare Center at Caderock. Caderock intends to request that funds from this project be redirected to other, new JTEV-related projects. CALSTART expects to submit the new proposed projects to DARPA for approval during the next quarter.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Characterize JTEV steering	5,000	5,000		**TBD**			
2	Redesign system	10,000	22,000		**TBD**			
4	fabricate new system	15,000			**TBD**			
5	test new system	8,000	5,000		**TBD**			
6	Final report	3,000			**TBD**			
		41,000	32,000					

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ROTARY ENGINE AUXILIARY POWER UNIT DEMONSTRATION

Project Manager: ***Aerobotics, Inc. a division of Moller International***
CS-AR95-07

Moller did little additional testing of the vehicle during the quarter. Testing under the current configuration, with batteries towed in a trailer behind the vehicle, is not expected to produce useful performance results. Moller continues to work with Bolder Technologies in an effort to obtain Bolder's batteries for use in the vehicle. The Bolder batteries would be installed in the trunk of the vehicle. Bolder had previously supplied batteries for this project. However, those batteries experienced a range of problems, the cause of which is still in question.

Moller expects to make a decision during this quarter as to the final disposition of this project. If Bolder batteries can be obtained, Moller indicates it will perform additional testing and perhaps additional optimization of its auxiliary power unit. If Bolder batteries are not available, then Moller may seek an alternative supplier, such as Hawker. However, Moller has not decided if it can commit the additional resources to accomplish necessary redesigns to accommodate a battery pack other than Bolder's.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Complete design	40,000	108,320	1	3/6/96	5/31/96	112,793	40,000
2	Order batteries/tooling	57,855		2	3/30/96	5/31/96	15,125	53,162
3	Finish block fabrication	25,000	46,500	3	5/15/96	12/30/96	6,188	38,490
4	Receive/Evaluate Geo Metro	16,495		4	8/16/96	8/25/96	23,531	46,201
5	Drivetrain/Engine Installation	37,500	37,500	5	10/4/96	12/96	30,000	22,489
6	Vehicle testing	23,492	15,000	6	12/15/96	3/30/97		
7	Final report	32,013	10,000	7	2/4/97			
		232,355	**217,320**				**187,6387**	**200,342**

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TURBO-GENERATOR FOR THE MOLLER ROTAPOWER ENGINE

Project Manager: ***Moller***
CS-AR97-08

CALSTART and Moller have not yet executed an agreement to commence this work. Because of recent changes in staffing at Moller, CALSTART intends to revisit the scope of work with Moller personnel during the next quarter. Ren Tubergen, the Moller Project Manager for this effort, is no longer with Moller. Based on next quarter's review, CALSTART will either execute a contract with Moller to begin the work, recommend proposed changes to the scope of work to DARPA, or decide not to proceed with the project.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Prepare for testing/heat study	17,500	17,500		**TBD**			
2	Turbine/Motor results	12,500	12,500		**TBD**			
3	Design/Final report	20,000	20,000		**TBD**			
		50,000	50,000		**TBD**			

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QUICK CHARGING SYSTEM WITH FLYWHEEL ENERGY STORAGE

Project Manager: ***Trinity Flywheel Battery***
CS-AR96-01

Don Bender and John Eastwood discusses the Trinity projects with Dr. Robert Rosenfeld of DARPA at a meeting April 1, 1998 at CALSTART. Slides from the discussion are available in the Appendix.

During the quarter, Trinity conducted approximately 30 test runs on the system that was integrated and activated the previous quarter. Trinity also made progress in control and communication. Trinity identified instabilities in startup control and revised the control algorithms. Trinity also selected a new enclosure style for the final system based on recent containment results and subsystems integration. Trinity built a prototype of the new enclosure and outfitted it with equipment.

Trinity is still actively pursuing a test site to replace the PG&E Modular Generation and Test Facility. Trinity expects to continue the test runs next quarter. Trinity will be attending the DARPA program review next quarter. CALSTART has been in constant communication with Trinity during the quarter and will be visiting their facility during the next quarterly reporting period.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
0	Initiate work	64,085	7,200		1/30/97	1/30/97	7,200	64,085
1	Flywheel/Interface/FESS/ LIU Specifications	119,298	45,600	1	3/30/97	3/30/97	45,600	45,600
2	Design review/initial testing	116,791	88,400	2	6/30/97	6/30/97	48,211	88,400
3	Manufacture/Phase 1 testing	37,895	320,146	3	9/30/97		263,247	67,634
4	Installation drawings/program review	137,618	28,800	4	12/31/97			31,455
5	Integration and initial check-out		33,900	5	3/30/98			
6	Final report	77,401	32,550	6	6/30/98			
	TOTALS	**553,088**	**556,596**				**364,258**	**297,174**

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MOBILE FLYWHEEL POWER MODULE

Project Manager: ***Trinity Flywheel Systems, Inc.***
CS-AR97-04

Don Bender and John Eastwood of Trinity discussed the project with Dr. Robert Rosenfeld of DARPA at a meeting April 1, 1998 at CALSTART.

Trinity and CALSTART worked out the milestones for the project during the quarter. The contract was successfully executed on 3/31/98 and work has progressed on the project. Due to the fact that the contract was pending for most of the quarter, Trinity has requested that more time to complete a first report (which would ideally have been provided at this time) in order to focus on the May DARPA review. Trinity also felt that they had provided information to Dr. Rosenfeld in the April 1, 1998 meeting which was attended by John Tripp, CALSTART project manager and John Boesel, CALSTART Executive Vice President in charge of programs.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Conceptual Design	100,000	65,000	1	3/13/98			
2	Detailed design	115,000	100,000	2	6/30/98			
3	Manufacturing	130,000	125,000	3	9/30/98			
4	Assembly and Checkout	100,000	180,000	4	12/31/98			
5	Testing and final report	50,000	100,000	5	3/31/99			
		495,000	570,000					

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ENVIRONMENTAL CONTROL SYSTEM FOR ELECTRIC AND HYBRID VEHICLES

Project Manager: ***Glacier Bay***
CS-AR96-02

Glacier Bay completed the project during the quarter and submitted a final report. The final report is included herein. A summary of the key results of this project, detailed in the final report, is provided below:

1. The air conditioning unit achieved an Energy Efficiency Ratio of 11.36 under severe driving conditions and 15.80 under average driving conditions, exceeding the project's goals by 5 percent.

2. The total weight of the Environmental Control System (ECS) is 60.82 pounds, which represents a 51.3 percent reduction in weight compared to a typical heating and air conditioning system.

3. The Glacier Bay ECS achieved a 100 percent hermetically sealed design, which will result in reduced maintenance and improved reliability compared to other heating and air conditioning systems.

4. The Glacier Bay ECS achieved an output of 5.97 kilowatts with its liquid circulating, fossil-fueled fired heater design, exceeding the design goal by 19 percent. Research performed by EVermont and others indicates that a minimum heater output of 5 kilowatts is necessary in extremely cold climates. The Glacier Bay ECS can operate on natural gas or propane.

5. The Glacier Bay ECS system can be adapted to operate at voltage inputs ranging from 98 to 425 volts of direct current. This is accomplished simply through the use of a wide input voltage motor controller. The ability to accommodate a wide range of voltages makes the Glacier Bay ECS more competitive by allowing it to capture low volume markets.

6. Glacier Bay met and exceed its cost share goals by $15,000.

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ENVIRONMENTAL CONTROL SYSTEM FOR ELECTRIC AND HYBRID VEHICLES

Project Manager: ***Glacier Bay***
CS-AR96-02

CALSTART will be working with Glacier Bay to further develop and commercialize this promising technology.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Initiate work	20,000			10/25/96			20,000
2	Design of Major Components	34,573	44,113	1	12/31/96	12/31/96	44,113	34,573
3	Prototype drawings complete	55,000	60,000	2	3/31/97	3/31/97	60,000	53,076
4	Production of major components	50,000	45,000	3	6/30/97	6/30/97	45,000	50,000
5	Prototype bench testing	17,000	21,000	4	9/30/97	9/30/97	21,000	17,000
6	Production/Testing prototypes	35,000	8,000	5	12/31/97	12/31/97		29,242
8	Final report	23,427	11,887	7	3/31/98	3/31/98	35,586	31,109
		235,000	190,000				205,699	235,000

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COOPERATIVE TESTING

Project Manager: ***Glacier Bay with EVermont***

Performance testing of the Glacier Bay Environmental Control System (ECS) was completed during the quarter. The detailed results of the testing are included in the final report submitted by Glacier Bay. The Solar Power Research Institute in Florida performed testing of the air conditioning unit. The University of California, Davis, performed testing of the fossil-fuel fired heater. Below are highlights of the testing.

The air conditioning capabilities of the ECS were tested by installing the ECS unit on a Geo Metro supplied by EVermont. A gasoline-powered Geo Metro was also tested to provide comparative data. The two cars were driven at the same time on two separate, pre-defined driving routes that included stop signs and traffic lights. Test results indicate the Glacier Bay ECS cooled the Geo Metro cabin more rapidly during the first seven minutes of the test. The gasoline-powered Geo Metro achieved slightly lower (two-to-three degrees Fahrenheit) overall cooling, but both vehicle maintained a comfortable cabin temperature despite high ambient temperature (91 degrees Fahrenheit) and solar radiation (760 watts per square meter).

The testing of the heating capabilities was designed to determine the heat output and emissions of the ECS. UC Davis ran two separate bench tests for the ECS heating system. In the first test, a positive displacement water pump was used to circulate a constant, known mass flow of water through the heating unit. Thermocouples recorded the change in temperature between the incoming and outgoing water to determine the temperature rise. In the second test, for emissions, the heater was connected to a finned coil air heat exchanger so that a stable, steady-state condition could be achieved at normal operating temperatures. The heater was activated and the discharged exhaust gas analyzed by a 5-gas emissions analyzer.

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COOPERATIVE TESTING

Project Manager: ***Glacier Bay with EVermont***

The test results indicated a heating capacity of 5.97 kilowatts. Research by EVermont and others indicate that a minimum output of 5 kilowatts is necessary to maintain comfortable cabin temperatures in cold climates. The ECS also demonstrated substantially reduced emissions compared to a diesel/kerosene heater manufactured by Webasto, as shown in the table below. The Webasto heater was used as a comparative base because it was one of only two fossil-fuel fired heaters that were capable of properly heating a vehicle in a test conducted under the Northeast Advanced Thermal Management Technology Project.

Pollutant	Diesel/Kerosene	Natural Gas/Propane
Nitrous Oxides	200 parts per million	24 parts per million
Hydrocarbons	100 parts per million	3 parts per million
Carbon Dioxide	10.5 percent	6.1 percent
Carbon Monoxide	0.2 percent	0.12 percent

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT) PROJECT

Project Manager: ***ISE Research***
CS-AR96-05

Mike Simon of ISE discussed the project with Dr. Robert Rosenfeld of DARPA at a meeting April 1, 1998 at CALSTART. Slides from the presentation are included in the Appendix.

ISER completed fabrication of the main drive motor components and delivered them to its subcontractor United Defense. An identical motor for a different vehicle was completed and delivered to ISER in late March. Subcontractor Siemens Corp. completed the initial testing of the AC motor control system. ISER held a progress review with Siemens to determine the status of that system.

ISER finalized the network architecture for the HEPT and initiated construction of the advanced distributed network modules. ISER completed the design of the battery racks and sent it to PACCAR (Kenworth parent company) for review prior to fabrication.

ISER also concluded negotiations and relocated the vehicle production to a new 5,610 square foot building. ISER currently hopes to complete assembly of the motor and integrate it into the HEPT in the middle of next quarter. ISER is now projecting vehicle completion in May 1998, two months later than previously scheduled. ISER also expects to complete the second hybrid electric prototype truck (HEPT) on 30 September, 1998.

ISER has continued to progress on a number of other projects that support development of the HEPT. These include upgrades to the United Airlines electric tow tractor; an all electric Sparkletts class 7 water delivery truck; three prototype hybrid-electric tow tractors for the U.S. Air Force and negotiating with the Los Angeles Department of Transportation to provide five hybrid-electric transit buses.

The additional projects and the second HEPT have been supported by additional money that has significantly increased the match funding on the project.

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HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT) PROJECT

Project Manager: ***ISE Research***
CS-AR96-05

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Drive system design approved. System controller design compete	30,000	96,700	1	1/10/97	1/10/97	95,443	30,000
2	System controller modules design. APU/genset integrated/tested	35,000	100,000	2	4/10/97	3/30/97	162,333	35,000
3	Vehicle integration plan complete	35,000	75,000	3	7/10/97	3/30/97		20,000
4	Major components integrated	30,000	50,000	4	10/10/97			15,000
5	Vehicle fully integrated/testing initiated	30,000	75,000	5	1/10/98			71,276
6	Phase 1 Operational testing complete	30,000	50,000	6	4/10/98		391,680	30,000
7	Commercialization plan initiated	30,000	25,000	7	7/10/98			
8	Phase 2 testing complete/Business plan approved	5,000	25,000	8	10/10/98			
9	Final report	25,000		9	1/10/99			
		250,000	**496,700**				**649,456**	**201,276**

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ELECTRIC VEHICLE LONG RANGE EXTENDING GENERATOR

Project Manager: ***AC Propulsion***
CS-AR96-06

Under the Electric Vehicle Range Extending Generator program, AC Propulsion sought to develop an off-board Auxiliary Power Unit (APU) that could be towed behind an electric vehicle. Prior to the launch of this program, AC Propulsion had not been able to identify a generator that provided the satisfactory combination of size, weight, output, and cost to meet the demands of vehicular application. In this program, AC Propulsion sought to test the Moller rotary engine as a generator and to complete work on various sub-systems critical to the operation of an off-board APU.

CALSTART has reviewed the final report and determined that AC Propulsion completed all of the tasks and has satisfactorily managed the program. In specific, AC Propulsion did the following:

1. Designed an alternator and charging control system to meet the project objectives;
2. Constructed a prototype charging system;
3. Tested prototype charging system;
4. Integrated the charging system and the Moller rotary engine;
5. Test and developed the integrated power train.

From these tasks, AC Propulsion generated the following **results and findings**:

- AC Propulsion was able to design a charging system that provides high specific output and high power density - critical elements for a hybrid-vehicle design. The charging system met or exceeded all project objectives. Continuous output of 20 kW at 300-390 volts was achieved at 7000 rpm. The alternator efficiency was measured at 91%.
- AC Propulsion now has a simple, robust, and low cost design for their alternator controller that achieves direct control of output with engine speed.
- After thorough testing, it was determined that the Moller rotary engine would not be suitable for hybrid or range extending applications. Power and efficiency are too low, and its current configuration is not well suited to direct-drive systems. Other thermal engines can be adapted more readily.

ELECTRIC VEHICLE LONG RANGE EXTENDING GENERATOR

Project Manager: ***AC Propulsion***
CS-AR96-06

In terms of future efforts, AC Propulsion is now ready to commercialize the charging system both as a stand-alone production with application to hybrid-electric drive systems, and as part of a range extending trailer to be towed behind EVs for long distance travel. AC Propulsion believes that its system is best suited for series-hybrid vehicle designs. However, most big auto manufacturers are pursuing parallel systems which represent fewer engineering challenges than the series-hybrid configuration. AC Propulsion advocates the series-hybrid configuration because it will allow the user to drive in a pure electric mode for short trips and will not require the use of an engine for these trips. AC Propulsion is hoping that operators of industrial equipment, buses, passenger vehicles, and some military vehicles may find benefits from series-hybrid operations.

With its range extending trailer, AC Propulsion has found a product that will provide for a vehicle with good fuel economy and low emissions. Using the range extending trailer, a vehicle could have a virtually unlimited range. Two major auto manufacturers have expressed interest in the trailer concept, and AC Propulsion plans demonstrations and additional development of the range extending trailer technology.

A copy of the AC Propulsion Final Report is in the Appendix.

CALSTART

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ELECTRIC VEHICLE LONG RANGE EXTENDING GENERATOR

*Project Manager: **AC Propulsion***
CS-AR96-06

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Design study complete	51,000	57,000	1	1/10/97	1/10/97	52,211	51,000
2	Prototype charging system constructed	72,000	53,000	2	4/10/97	3/30/97	46,600	72,000
3	Moller engine delivered	22,000	25,000	3	7/10/97	8/30/97	25,000	30,000
4	Integration complete	8,000	11,000	4	10/10/97	9/30/97	11,000	
5	Testing complete	8,000	15,000	5	1/10/98	12/31/97	15,000	
6	Final report	9,000	9,000	6	4/10/98	3/5/98	9,000	17,000
	TOTALS	**170,000**	**170,000**				**170,000**	**170,000**

CALSTART

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ENGINEERING IMPROVEMENTS FOR PURPOSE-BUILT EV

*Project Manager: **PIVCO***
CS-AR96-07

There is no change from last quarter. A contract has been sent to PIVCO. An updated statement of work and milestone chart will be provided in the next quarterly report.

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DISTRIBUTED ENERGY MANAGEMENT SYSTEM (DEMS) DEVELOPMENT AND DEMONSTRATION

Project Manager: ***Raytheon (FKA: Hughes Technical Services Center)***
CS-AR96-08 and CS-AR94-04

Jeff Taylor and Steve Ables met with DARPA representatives including Dr. Robert Rosenfeld at CALSTART on April 1, 1998. Slides from this discussion are included in the Appendix.

Raytheon is currently working on final report preparation of the project. This report should be completed prior to the end of the next quarter. During the quarter, Raytheon reinstalled the controllers on two of the Greater Richmond Transit buses. The controllers had been removed for modifications, which were completed by Raytheon.

Access to these buses for testing continues to be extremely limited because of continuing brake problems. BlueBird and Northrop continue to negotiate on a solution for this problem. Raytheon was able to charge the battery packs on the bus using the multi-controller system. Preliminary results indicate that the multi-controller system, which controls at the battery pack level, allows problems with individual batteries to be isolated more quickly.

Raytheon will continue to provide support for the Greater Richmond Transit buses after the conclusion of this project. Raytheon hopes to gather additional operating data from the buses once the brake problem is resolved and the buses are placed back in service.

Work on the Distributed Energy Management System (DEMS) is complete. DEMS was tested in a laboratory setting and results indicate that the DEMS is performing as designed, including compensating for different battery voltage levels during charging. Testing has identified additional improvements that could improve performance of the DEMS. However, such improvements are not part of the scope of work for this project.

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DISTRIBUTED ENERGY MANAGEMENT SYSTEM (DEMS) DEVELOPMENT AND DEMONSTRATION

Project Manager: ***Raytheon (FKA: Hughes Technical Services Center)***
CS-AR96-08 and CS-AR94-04

	MILESTONES CS-AR94-04	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Requirements defined. Concept for controller hardware defined	30,000	50,000	1	6/30/96	6/30/96	281,022	50,000
2	Software defined and programmed.	30,000	50,000	2	9/30/96	9/30/96	150,979	50,000
3	Design/Implementation of multiple pack system controller	70,000	370,000	3	12/31/96	12/31/96	15,474	150,000
4	Software installed on 25kW Inductive Opportunity Charge system.	50,000	15,000	4	3/30/97	3/30/97	146,051	
5	Bluebird buses equipped Field data acquired	70,000		5	6/30/97			
		250,000	**485,000**				**593,526**	**250,000**

	MILESTONES CS-AR96-08	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
5	Task continued: DEMS upgrade concept complete/controller built	200,000	108,000	5	6/30/97			
6	Final report.	50,000	15,000	6	9/30/97			
		250,000	**123,000**					

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HIGH POWER CHARGING SYSTEM FOR ELECTRIC VEHICLES

Project Manager: ***General Motors Advanced Technology Vehicle***
CS-AR97-07

General Motors Advanced Technology Vehicles (GM ATV) and CALSTART signed the contract officially beginning the program during the quarter.

Prior to the official signing of the contract, GM ATV commenced work on the project statement of work. As such, the project remains on schedule despite the delays in executing the contract. CALSTART has attended numerous program reviews at GM ATV to discuss the program status. GM ATV also prepared a prototype of the high power charging system for EVS 14 in December, 1997.

GM ATV has completed the design of the system enclosure. GM ATV has also modified the Gen 2 SCM packaging so that nine 6.6 kW units will fit into an enclosure the same size as the one prepared for EVS 14.

GM ATV has nearly completed the design and drawings of the SCM chassis. GM ATV is also 75% finished with the design and drawings for the master controller module (MCM). Work has also begun on the power bus raceway and bus bar design.

GM ATV has taken delivery of all the cooling system parts as well. GM ATV has completed the schematic designs for the master controller board, LCD module adapter board, DOOC adapter board for design test, and DOOC bench test tool. GM ATV has completed the layout and net routing of the PCB for the master controller board. GM ATV has also completed the PCB and PCB manufacturing for the LDC module adapter board and DOOC adapter board.

DOOC tool fabrication was completed and the tool was checked out. GM ATV has nearly completed the modular design of the DOOC LCD design functions and designed the main CPU interface. GM ATV has also completed construction of one of the 6.6 kW SCM units and is 90% complete with 12 others.

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HIGH POWER CHARGING SYSTEM FOR ELECTRIC VEHICLES

Project Manager: ***General Motors Advanced Technology Vehicle***
CS-AR97-07

GM ATV has also made significant progress on and settled on a number of design features for the charger. A NiMH truck will be available for the program as of November 1, 1998. One charge port and conversion box set was shipped to GM ATV in Troy, MI in late March. Four more sets are due to be shipped in the first few weeks of next quarter. CALSTART will continue to attend regular program reviews during the next quarter, approximately monthly.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	System Requirements	31,790	178,388	1	9/30/97			
2	Charger Fabrication	58,582	328,730	2	12/31/97			
3	Charger Test/CP/CV Fabrication	94,681	531,300	3	3/31/98			
4	Installation of operational hardware/software	119,815	672,388	4	6/30/98			
5	Charger Installed	28,540	160,149	5	9/30/98			
6	Charger System Test	26,549	149,243	6	12/31/98			
7	Analysis and Test results	40,043	72,352	7	2/1/99			
		400,000	2,092,550					

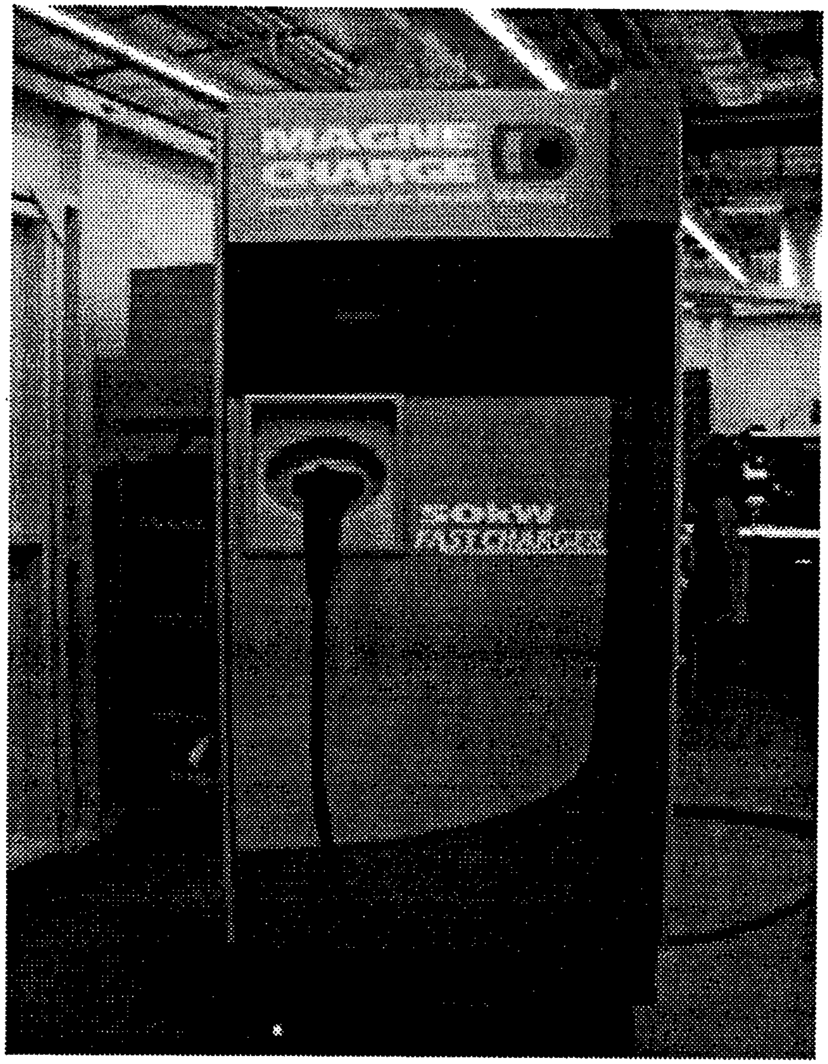

Figure 1 (50 kW Charger Photo)

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NOVEL, COMPACT AND EFFICIENT TESLA GAS TURBINE HEAT ENGINE

Project Manager: ***FAS***
CS-AR97-09

CALSTART met with FAS and executed a contract for this project during this quarter. FAS presented test material to the CALSTART program manager showing the work completed prior to final execution of the contract. FAS previously completed adaptation of the computer code for analysis of the turbine, compressor rotors and other key components.

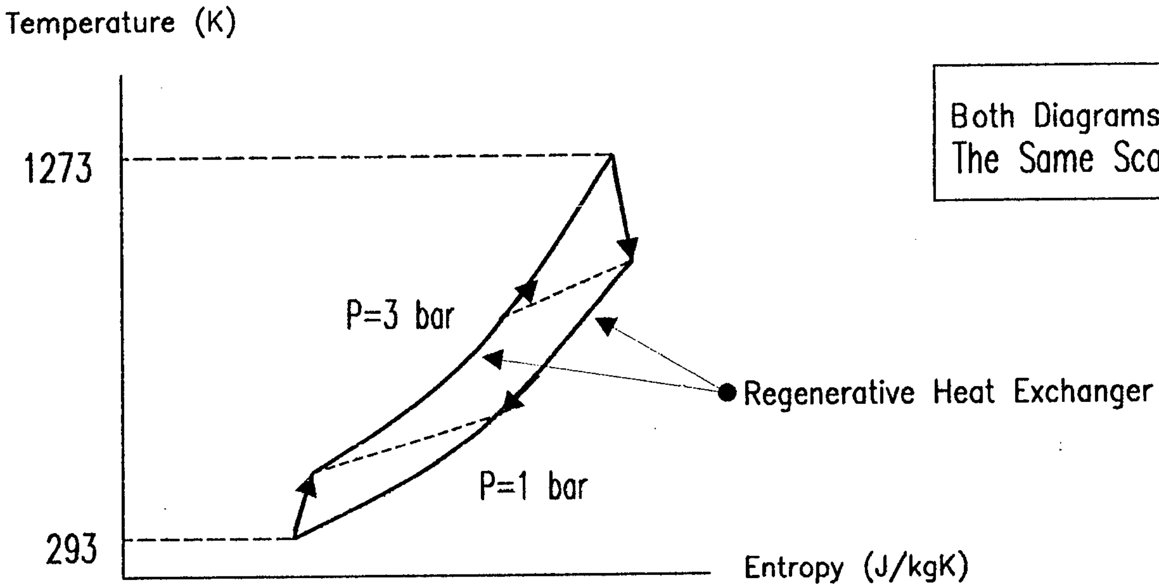
During current quarter, FAS discovered that by utilizing anisotropic porosity, it is possible to eliminate the need for tapering the rotors, resulting in reduced manufacturing and lower costs. FAS has also improved the computer code including allowing for simultaneous heat transfer in the compressor rotor. FAS has chosen to use hand calculations of thermodynamic cycles rather than an existing computer code after determining that no existing code is suitable for the cycles being used.

Next quarter, FAS hopes to adapt the thermodynamic calculation code to handle staged combustion and staged turbine expansion. Additionally, they will investigate the performance of compressor and turbine impellers. FAS will also evaluate the performance of stationary and rotating bladings.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Acquire/adapt computer codes	30,000	30,000	1	12/31/97	12/31/97	21,466	17,665
2	evaluation/derive improved heat exchanger	40,000	44,000	2	3/31/98			
3	Detailed design	40,000	42,000	3	6/30/98			
4	Final report	15,000	9,000	4	9/30/98			
		125,000	125,000				**21,466**	**17,665**

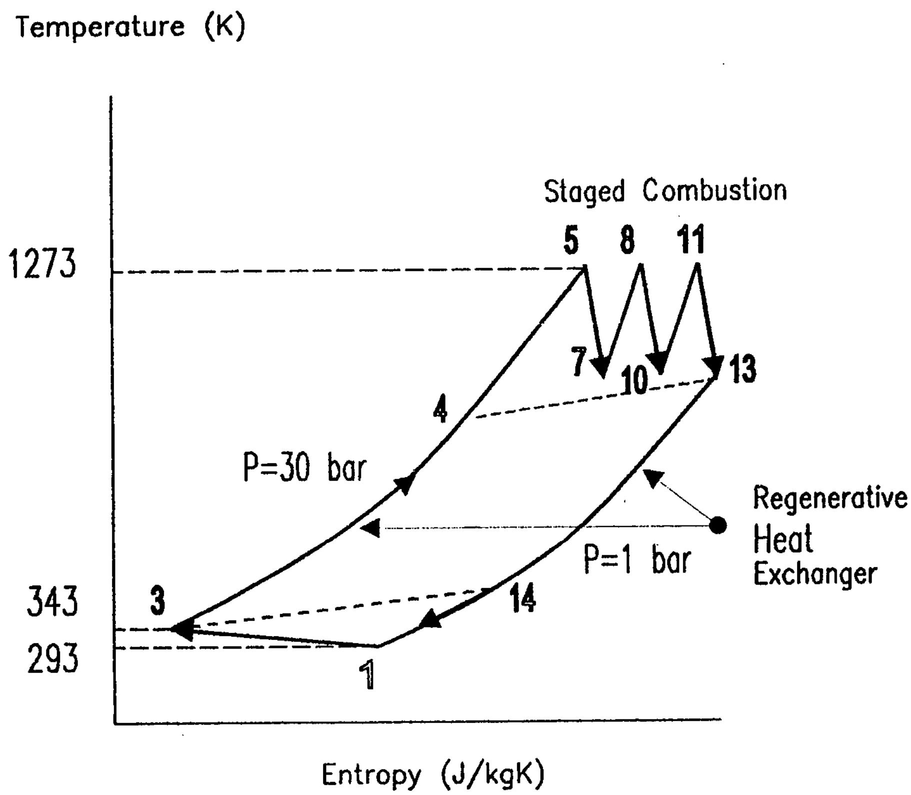
T-S DIAGRAMS FOR GAS TURBINE HEAT ENGINE

A) Conventional with Regenerative Heat Exchanger, Pr=3



Both Diagrams On The Same Scale

B) ATTHE with Compressor Cooling and Staged Combustion, Pr=30



Fluid Parameters

State	Temp(K)/Press(Bar)
1	293/1
3	343/30
4	745/30
5	1273/30
7	899/9.16
8	1273/9.16
10	900/2.83
11	1273/2.83
13	945/1
14	543/1

Viewgraph 1

FLUID STATE PARAMETERS

Mass Flow Rate = 0.03811 kg/s

State	Temperature(K)	Pressure(Bar)	Comment
1	293	1	Compressor Inlet
2	343	13.25	Compressor Rotor Exit
3	343	30	Compressor Exit
4	745	30	Regenerator Exit # 1
5	1273	30	1st Stage Inlet
6	1071	16.36	1st Stator Exit
7	899	9.16	1st Stage Exit
8	1273	9.16	2nd Stator Inlet
9	1071	4.99	2nd Stator Exit
10	900	2.83	2nd Stage Exit
11	1273	2.83	3rd Stator Inlet
12	1071	1.55	3rd Stator Exit
13	945	1	3rd Stage Exit
14	543	1	Regenerator Exit # 2

PROJECTED EFFICIENCIES OF 20kW GAS TURBINE HEAT ENGINE (T_{TOP}=1000 DEGREE CELSIUS)

Conventional Pr=3 Regenerative

	Turbine	Compressor	Overall
Efficiencies	75%	65%	20%

ATTHE Pr=3, No Compressor Cooling

	Turbine	Compressor	Overall
Efficiencies	85%	75%	27%

ATTHE Pr=3, Compressor Cooling

	Turbine	Compressor	Overall
Efficiencies	85%	75%	33.7%

ATTHE Pr=10, Compressor Cooling, Staged Combustion

	Turbine	Compressor	Overall
Efficiencies	85%	75%	42.5%

ATTHE Pr=30, Compressor Cooling, Staged Combustion

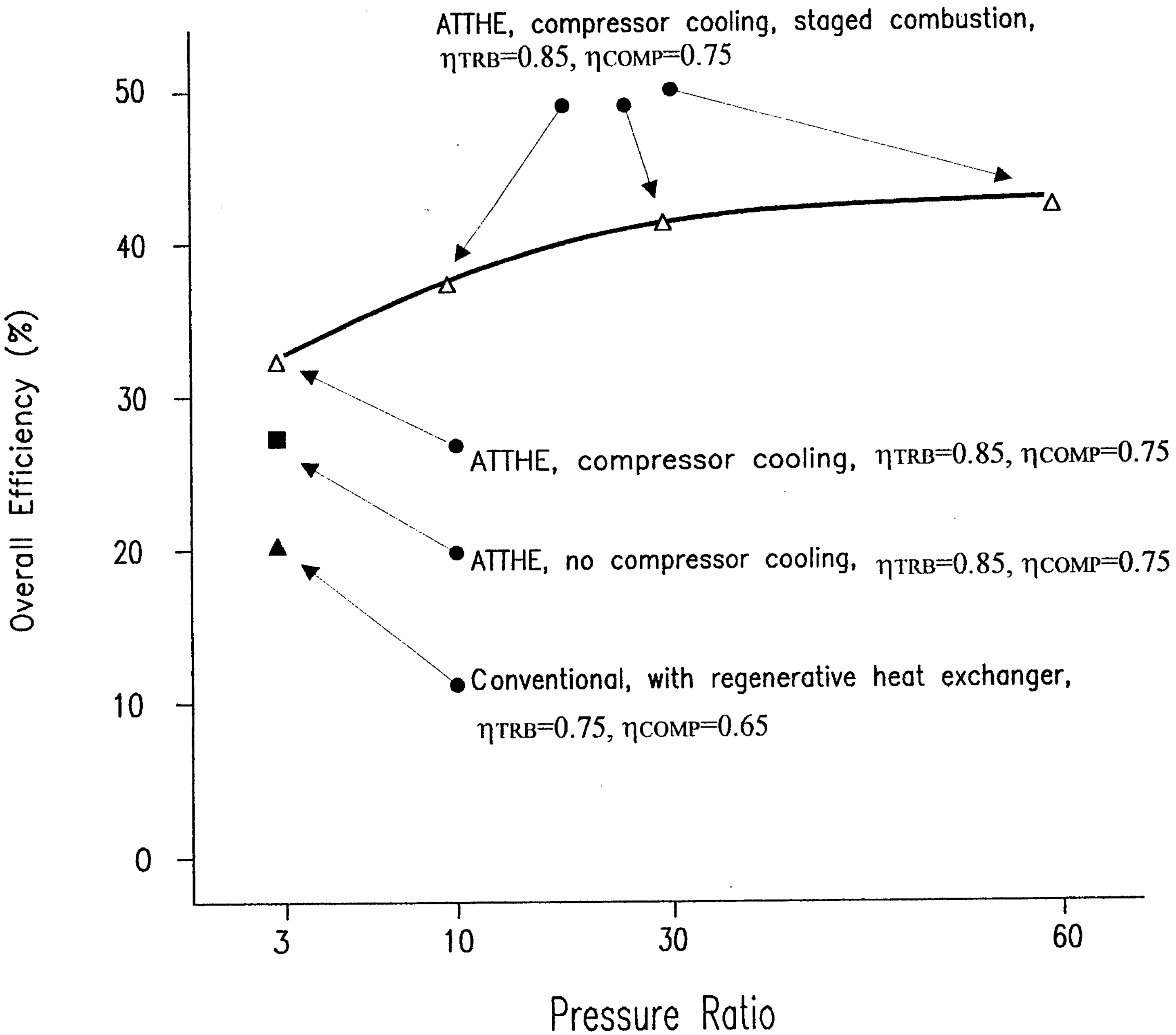
	Turbine	Compressor	Overall
Efficiencies	85%	75%	46.1%

ATTHE Pr=60, Compressor Cooling, Staged Combustion

	Turbine	Compressor	Overall
Efficiencies	85%	75%	47.5%

OVERALL EFFICIENCIES OF 20kW ATTHE HEAT ENGINE

TOP FLUID TEMPERATURE IS 1000 DEGREE CELSIUS



Viewgraph 4

Reasons For Higher Impeller Efficiencies of Porous than of Conventional Bladed Rotors

- Pores much smaller than usual inter-blade passages; therefore fluid flows better accommodates to detailed shape of the rotor, i.e. lower losses due to turbulence and secondary flows in passages

- Much lower boundary layer and wakes fluid dynamic losses.

- Much lower blade leading edge heating

- Lower fluid leak about the rotor losses. This is due much to higher number of "blades" in porous rotor cases or due to solid side hubs.

- Fluid dynamic unsteadiness in the rotor reduced.

- More uniform flow at the rotor exit.

DEVELOP AND DEMONSTRATE A HYBRID-ELECTRIC TRANSIT BUS

Project Manager: ***Foothill Transit***
CS-AR97-10

Fred Haley from Foothill attended the DARPA program review at CALSTART and presented to Dr. Robert Rosenfeld, Ryan Gallagher and Danny Jordan of DARPA. Slides from the April 1, 1998 meeting are included in the Appendix.

Fred Haley is the new Program Manager for this effort. Foothill indicated its desire to change the fuel type for the auxiliary power unit. Due to the reasons of accessibility, familiarity, and cost, Foothill would prefer to use diesel rather than natural gas as a fuel. DARPA Program Manager Bob Rosenfeld indicated this change would be acceptable and would make the technology more applicable to DARPA's military interests. Foothill staff is awaiting final approval from their Board of Directors before making the final decision to go with diesel.

CALSTART is working with Foothill Transit to set the statement of work and scope for the Gillig Phase Two hybrid-electric bus. CALSTART expects to put this program under contract sometime next quarter.

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ASSESSMENT OF ADVANCED ENGINE TECHNOLOGIES FOR UAV AND HEV APPLICATIONS

Project Manager: ***FEV Engine Technology***
CS-DARO-02

FEV continued its assessment of the Engine Corporation of America (ECA) Turbo-Electric Compound Engine (TECE) and also continued testing of its 2-stroke, single-cylinder engine. Both of these tasks were nearly complete at the conclusion of this quarter. However, the compilation of the results is not yet complete. The next quarterly report will include FEV's final report and a summary of the key findings.

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	TECE Thermo/Mech Assessment	50,000	50,000	1	9/30/97	9/30/97	50,000	50,000
2	2/4 Stroke Concept Assessment	250,000	470,000	2	12/30/97	12/30/97	470,000	200,000
3	2.4 Stroke Demo. Final Report	700,000	480,000	3	3/30/98		638,902	
	TOTAL	**1,000,000**	**1,000,000**				**1,158,902**	**250,000**

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HEAVY FUEL ENGINE (HFE) TEST PROGRAM

Project Manager: ***General Atomics Aeronautical Systems, Inc.***
CA-DARO-01

During the quarter, General Atomics made progress on engine subsystem testing, basic test series on the engine, and limited durability testing on the engine. General Atomics has completed design of the low altitude simulation system. However, significant changes to the new test facility are being contemplated. These changes, and progress toward completion of the project are discussed below.

Engine Subsystem Testing

The engine mounted fuel injection system has been satisfactorily completed and is now integrated on the engine. The supercharger system is being redesigned due to unsatisfactory performance. General Atomics is participating in the redesign with its subcontractor and expects to test the redesigned supercharger in April. No testing of the wastegate control system has been completed. The wastegate control system is not necessary until testing under simulated or real altitude conditions is performed. However, General Atomics indicates that continued modeling of the engine indicates that the wastegate control system might not be needed.

Basic Test Series

The three cylinder engine has accumulated approximately 6 hours of run time. The engine has been run over the entire speed range and at up to 75 horsepower, one-half of the rated power. Continued problems with the supercharger prevent General Atomics from running the engine at full power. The third iteration of the supercharger will be operational in April. Oil scavenge problems were encountered where too much oil was remaining in the engine during running and was not adequately being returned to oil tank. General Atomics has made some progress in resolving, and expects that further refinements will fix, this problem. The turbocharger is operating better than expected, and the fuel injection system is performing successfully.

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HEAVY FUEL ENGINE (HFE) TEST PROGRAM

Project Manager: ***General Atomics Aeronautical Systems, Inc.***
CA-DARO-01

Limited Durability Test

Single cylinder testing has been completed and provided beneficial information. The single cylinder engine completed a 53-hour test series that included nearly 37 hours of operation at 57 to 58 horsepower. While excessive piston ring wear was encountered during the testing, General Atomics does not consider this a major problem because of the length of time the rings are able to run without performance degradation. The piston rings will be the subject of future durability improvement tests using the single cylinder engine.

Low Altitude Simulation System

The layout design and associated subcomponent testing for the low altitude simulation system has been completed. Procurement activities are beginning in combination with detailed design.

New Test Facility

General Atomics had originally proposed renovating its existing test facility as part of this project. However, General Atomics now plans to buy a 50,000 square foot building located next door to its existing facility. General Atomics indicates that it will build a new test facility in that building. Therefore, the test facility will not be completed until June. This will not cause a delay in the overall program, as the test cell is only needed for propeller testing which is scheduled for late summer.

During the next quarter, General Atomics expects to complete the basic test series on the engine, complete limited durability testing, fabricate the low altitude simulation system and optimize systems in order to establish a baseline.

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HEAVY FUEL ENGINE (HFE) TEST PROGRAM

*Project Manager: **General Atomics Aeronautical Systems, Inc.***
CA-DARO-01

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Progress of sub-system testing, review of engine test facilities and plan for testing of advanced powerplant subsystem.	0	50,000				50,000	
2	Powerplant integrated to existing dynamometer. Subsystem test complete.	0	75,000				75,000	
3	Completion of low altitude simulation system. Completion of renovations. Commissioning of new propeller stand facility. Systems function - basic series. Systems optimization completed for baseline. Sea level mapping complete.	300,000	300,000					109,741
4	Powerplant integrated to propeller test stand. Low altitude simulation mapping complete. Propstand limited durability demonstrated.	50,000	75,000					
5	Continued Progress	50,000	0					
6	Continued Progress	50,000	0					
7	Demonstrated fuel injection durability maturation.	50,000	0					
	TOTAL	**$500,000**	**$500,000**				**$125,000**	**$109,741**

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PROGRAM MANAGEMENT AND ADMINISTRATION

Program Manager: ***CALSTART***

During this past quarter CALSTART focused its efforts on three major activities related to this Cooperative Agreement.

First, CALSTART worked with DARPA Program Manager Dr. Rosenfeld to prepare for the DARPA Program Review held at CALSTART on April 1, 1998. At that review eight companies presented eight different technologies. CALSTART worked with Dr. Rosenfeld to identify which projects should be presented then worked with each company to prepare their presentation. CALSTART staff appreciates such opportunities for these on-site reviews to learn more about how their programs fit into the larger DARPA EHEV Technology Development agenda.

One of the issues that CALSTART staff took the opportunity to present to Dr. Rosenfeld was the closeout of the Rockwell/Rocketdyne Safe Electro-Mechanical Batteries project funded in 1995 by modification P00004 to Agreement #MDA972-95-2-0011. Wayne Asp of Rocketdyne had notified CALSTART that approximately 500 pounds of stainless steel remained from the project and asked for clarification regarding disposal of the material. Dr. Rosenfeld stated that the stainless steel should be liquidated (either scrapped, sold, or incorporated for use by Rocketdyne). He stated that the documented value of the stainless steel should then be deducted from the overall project costs and the closeout should proceed. The CALSTART Contract Administrator has since relayed that information to Rocketdyne and Wayne Asp is preparing appropriate close-out documents. The opportunity to discuss this situation informally expedited the program closeout.

Slides from the various presentations at the April 1 meeting are included in the Appendix for further reference.

Second, CALSTART has committed significant resources to organizing the next DARPA Program Review which will be held in Pasadena from May 3-6, 1998. CALSTART will host this program review. In addition to arranging the 150+ Poster Sessions, CALSTART has also arranged to have outside speakers such as John Dunlap, Chairman of the California Air Resources Board, DOT and DOE Representatives, and Mark Amstock of the Toyota Corporation of America.

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PROGRAM MANAGEMENT AND ADMINISTRATION

Program Manager: ***CALSTART***

The third program management activity has been working with DARPA to determine the best way to use FY98 funds to develop related technologies under this program. CALSTART identified a number of recommended program extensions to Dr. Rosenfeld and is working with him and his staff to select the best ones. CALSTART staff traveled to Arlington, Virginia on February 24, 1998 to review the options with Dr. Rosenfeld and consultants Danny Jordan and Ryan Gallagher.

CALSTART also played a major role in the roll-out of the APS Systems 40' Hybrid Electric Bus. The bus utilizes the DARPA funded Alturdyne rotary engine as the auxiliary power unit. Alameda Contra/Costa (AC) Transit is demonstrating the bus throughout its service territory. AC Transit has informed CALSTART that its customers are extremely pleased with the performance, low emissions, and low noise level of the bus. CALSTART helped stage the roll-out of the prototype bus at the AC Transit Oakland service depot.

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PROGRAM MANAGEMENT AND ADMINISTRATION

Program Manager: ***CALSTART***

	Milestones	DARPA	MATCH	QTR	DATE DUE	COMPLETE	DARPA FUNDS EXPENDED
94	Program Management	369,000					369,000
	CS-AR94-08	369,000	0				369,000

95	Program Management CALSTART	203,394					203,394
	CS-AR95-99	203,394	0				203,394

96	Program Management CALSTART	188,502					140,983
	CS-AR96-10	188,502	0				140,983

Mod 8	Program Management CALSTART	53,000					15,000
	CS-AR97A-99	53,000	0				15,000

Mod 9	Program Management CALSTART	124,000					74,500
	CS-AR97-99	124,000	0				74,500

Mod 11	Program Management CALSTART	50,000					15,000
	CS-AR97A-99	50,000	0				15,000

Mod 12	Program Management CALSTART	256,700					35,000
	CS-AR97A-99	256,700	0				35,000

CALSTART

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APPENDIX

COST REPORTING SUMMARY AND DETAIL

COMPLETED PROJECTS

CANCELED PROJECTS

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COST REPORTING SUMMARY AND DETAIL

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
94	CS-AR94-01	**Running Chassis II Amerigon**		700,000	4,098,410	X	06/30/97	07/31/97	700,000
94	CS-AR94-02	**M300DC Motor Speed Controller Jefferson Programmed Power**		217,000	217,000	X	07/10/96	09/20/96	217,000
94	CS-AR94-03	**HD Hybrid Electric Drive Train SBAPCD**		29,568	9,856	X		05/22/97	29,568
94	CS-AR94-04	**Distributed Energy Management System Hughes Technical Services Company nka RAYTHEON**		250,000	485,000	X			
94	CS-AR94-05	**HEV Battery System Bolder Tech**							0
94	CS-AR94-06	**Catalytic Combuster/Hybrid Electric Bus Capstone**		300,000	300,000	X	12/30/96		268,250
94	CS-AR94-07	**Hybrid Electric Air Emission Study NRDC/ACUREX**		100,000	100,000	X	11/01/96		63,000
94	CS-AR94-08	**Program Management CALSTART**		369,000					369,000
94	CS-AR94-12	**Data Acquisition CALSTART**		150,000				3/31/97	150,000
94	CS-AR94-13	**Energy Management Controller DELCO/Hughes Aircraft**		18,000		X		08/01/95	18,000
94	CS-AR94-91	Re-allocated in Mod 12 to Mod 4 Moller		30,505					
94	CS-AR94-92	Re-allocated in Mod 12 to Mod 8 Trinity PM		53,000					
94	CS-AR94-93	Re-allocated in Mod 11		90,000					
94	CS-AR94-94	Re-allocated in Mod 12 to Mod 12		1,196,927					
94 Total				**3,504,000**	**5,210,266**				**1,814,818**

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
94.3	CS-AR94-09	**Project Hatchery North CALSTART**	0003	150,000	135,000				150,000
94.3	CS-AR94-10	**NAS Planning Grant CALSTART**	0003	250,000					250,000
94.3 Total				**400,000**	**135,000**				**400,000**

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FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
95	CS-AR95-01	Flywheel Mag Loss Min Bearing AVCON	0004	126,349	126,349	X	06/15/94		126,349
95	CS-AR95-02	Flywheel Life-Cycle Testing Battery US Flywheel	0004	400,000	1,600,000	X	05/07/96		366,257
95	CS-AR95-03	Compact Low Cost Relays Coriolis	0004	100,000	100,000				
95	CS-AR95-04	Alturdyne Rotary Engine/Bus Demo Advanced Propulsion Systems	0004	65,000		X			58,500
95	CS-AR95-05	Safe Electro-Mechanical Batteries Rockwell	0004	259,500	783,000	X	09/30/96		177,325
95	CS-AR95-06A	Adv. Hybrid Recon Propulsion System Rod Millen Motorsport	0004	316,149		X	02/28/97		316,149
95	CS-AR95-06B	Adv. Hybrid Recon Propulsion System AeroVironment	0004	583,854	91,492	X	08/15/97		525,464
95	CS-AR95-07	Rotapower Engine Moller International with $30,505 allcated in Mod P00012	0004	232,355	217,320	X	02/04/97		200,342
95	CS-AR95-07	Re-allocation from mod 4	P00012	-30,505					
95	CS-AR95-99	Program Management	0004	203,394					203,394
95 Total				2,256,096	2,918,161				1,973,780

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
		High Efficiency Air-Conditioning							
96	CS-AR96-02	Glacier Bay	P00007	235,000	190,000	X	04/10/98		203,891
96	CS-AR96-04	E/HEV Manufacturability CALSTART	P00007						
96	CS-AR96-05	Prototype Hybrid Electric Truck ISE	P00007	250,000	496,700	X	07/10/98		201,276
96	CS-AR96-06	EV Range Extender AC Propulsion	P00007	170,000	170,000	X	04/10/98		170,000
96	CS-AR96-07	Purpose Built EV Engineering Pivco	P00007	150,000	350,000				
96	CS-AR96-08	Distributed Energy Mgmt System Hughes Technical Services Company nka RAYTHEON	P00007	250,000	123,000	X	03/30/97		250,000
96	CS-AR96-09A	Adv HE Recon Veh AeroVironment	P00007	359,712		X			84,235
96	CS-AR96-09B	Adv HE Recon Veh Rod Millen	P00007	270,304	36,000	X	03/30/98		132,596
96	CS-AR96-10	Program Management CALSTART	P00007	188,502		X			140,983
96	CS-AR96-96	Re-allocated in Mod 12	P00007	200,000					
96 Total				2,073,518	1,365,700				1,182,981

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
96.8	CS-AR96-01	**Quick Charging Systems**	P00008	553,088	556,596	X	06/30/98		297,174
96.8	CS-AR96-99	**Reallocation from RA-94 in mod 12**	P00012	-53,000					
96.8	CS-AR96-99	**Program Management - CALSTART**	P00012	53,000					15,000
96.8 Total				**553,088**	**556,596**				**312,174**

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
97	CS-AR97-01	JOINT TACTICAL EV-FUEL EFFICIENCY TESTING AeroVironment	P00012	100,920	0				
97	CS-AR97-02	JOINT TACTICAL EV-HYBRID ALGORITHM AeroVironment	P00012	76,276	0				
97	CS-AR97-03	JOINT TACTICAL EV-PERIPHERALS DEV Rod Millen Special Vehicles	P00012	41,000	32,000				
97	CS-AR97-04	MOBILE FLYWHEEL POWER MODULE Trinity Flywheel	P00012	495,000	570,000	X			
97	CS-AR97-05	FLYWHEEL SHOCK TESTING US Flywheel	P00012	450,000	450,000	X			114,243
97	CS-AR97-06	HYBRID VEHICLE TURBOGENERATOR w/LIQUID FUELED CATALYTIC COMBUSTOR Capstone	P00012	302,000	784,750				
97	CS-AR97-07	HIGH POWER EV CHARGING SYSTEM - GMATV	P00012	400,000	2,092,500	X			
97	CS-AR97-08	TURBOGENERATOR FOR MOLLER ROTAPOWER ENGINE Moller	P00012	50,000	50,000				
97	CS-AR97-09	TESLA GAS TURBINE HEAT ENGINE FAS Engineering	P00012	125,000	125,000	X			17,665
97	CS-AR97-10	DEV/DEMO HYBRID TRANSIT BUS Gillig/Foothill Transit	P00012	200,000	455,000				
97	CS-AR97-11	MAGNETIC BEARING COMMERCIALIZATION Avcon	P00012	75,000	75,000				
97	CS-AR97-12	HEAVY DUTY VEH IND ANALYSIS CALSTART	P00012	181,829	0				40,000
97	CS-AR97-14	DARPA INTERNET LISTINGS CALSTART	P00012	70,000	0				17,500
97	CS-AR97-97	Re-allocation from Mod 7	P00012	(200,000)					
97	CS-AR97-98	Re-allocation from RA94	P00012	(1,196,927)					
97	CS-AR97-99	PROGRAM MANAGEMENT CALSTART	P00012	256,700	0				35,000
97 Total				1,426,798	4,634,250				224,408

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
97.09	CS-DARO-02	Assessment of Advanced Engine Technologies for UAV and HEV Applications FEV ENGINE TECH.	P00009	1,000,000	1,000,000	X			250,000
97.09	CS-DARO-03	Fuel Injector for UAV and HEV Engine Corporation of America	P00009	245,000	245,000	X			245,000
97.09	CS-DARO-98	Program Management CALSTART	P00009	124,500					74,500
97.09 Total				**1,369,500**	**1,245,000**				**569,500**

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Reallocations are shown in the year of the original allocation and in the year of the new project.

FY	Proj.No	PROJECT TITLE	Mod. No.	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
97.11	CA-DARO-01	**Heavy Fuel Engine Test - General Atomics**	P00011	500,000	500,000	X			109,741
97.11	CA-DARO-04	**Internet Program - CALSTART**	P00011	90,000					45,000
97.11	CA_DARO-04	**Re-allocation**	P00012	-90,000					
97.11	CS-DARO-99	**Program Management - CALSTART**	P00011	50,000		X			15,000
97.11 Total				**550,000**	**500,000**				**169,741**
Grand Total				**12,133,000**	**16,564,973**				**6,647,402**

Yearly totals reflect the amount of modifications sent by E. Ely.
Reallocations are shown in the year of the original allocation and in the year of the new project.

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR94-01	1	Initiate work	200,000		1	11/14/95	11/21/95	75,000
CS-AR94-01	2	Complete breadboard designs of drive train, running chassis, steel space frame	175,000		2	12/31/95	12/15/95	103,222
CS-AR94-01	3	Fabricate EV4 & BEV prototype parts Revise design pakgs	125,000		3	3/31/96		
CS-AR94-01	4	Complete all BEV vehicle tests. Revise tools.	40,000		4	6/30/96	7/8/96	270,000
CS-AR94-01	5	Complete build of EV4. Complete EV4 tests.	0		5	9/30/96	9/30/96	36,000
CS-AR94-01	6	Complete (begin tests) first productionized drive train.	0			12/31/96	12/31/96	
CS-AR94-01	7	Complete Finite Element Analysis and design of running chassis BEV.	0			3/30/97	4/30/97	71,778
CS-AR94-01	8	Complete build of 4 alum BEV's w/o body panels - 2 welded frames. Complete build/test 5 productionized drive trains. Complete comparative analysis. Complete final report.	160,000	4,098,410	6	6/30/97	7/31/97	144,000
CS-AR94-01 Total			700,000	4,098,410				700,000
CS-AR94-02	1	Design complete	72,000		1	10/10/95	10/25/95	72,000
CS-AR94-02	2	CPU Logic Board operational	65,000	80,000	2	1/10/96	1/11/96	65,000
CS-AR94-02	3	1st prototype controller test	50,000	60,000	3	4/10/96	4/17/96	58,300
CS-AR94-02	4	Final report	30,000	77,000	4		9/20/96	21,700
CS-AR94-02 Total			217,000	217,000				217,000
CS-AR94-03		No milestone - program canceled	29,568	9,856	X	6/15/95		29,568
CS-AR94-03 Total			29,568	9,856				29,568

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR94-04	1	Delco - See CS-AR96-08 Requirements defined; concept for controller hardware defined	30,000	50,000	1	6/30/96	6/30/96	50,000
CS-AR94-04	2	Software defined/programmed	30,000	50,000	2	9/30/96	9/30/96	50,000
CS-AR94-04	3	Design/Implementation of multiple pack system controller	70,000	370,000	3	12/31/96	12/31/96	150,000
CS-AR94-04	4	Software installed on charge system	50,000	15,000	4	3/30/97	3/30/97	
CS-AR94-04	5	Bluebird Buses equipped; Field data acquired; DEMS upgrade concept complete/controller built	70,000		5			
CS-AR94-04 Total			250,000	485,000				250,000
CS-AR94-05		No milestone - program canceled						
CS-AR94-05 Total			0	0				0

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR94-06	0	Initiate work	40,000	40,000		8/30/95	12/15/95	36,000
CS-AR94-06	1	Vandenburg Combuster/Monolith Test Rig	102,500	102,500		12/31/95	1/11/96	92,250
CS-AR94-06	1	Hardware/Electrical Designs	50,000	50,000	1	12/31/96	1/11/97	50,000
CS-AR94-06	2	Vehicle Integration	80,000	80,000	2	3/30/97	3/30/97	90,000
CS-AR94-06	3	System Integration	20,000	20,000	3	6/20/97		
CS-AR94-06	4	Final report	7,500	7,500	4	9/30/97		
CS-AR94-06 Total			300,000	300,000				268,250
CS-AR94-07	1	Refine study design.	20,000	20,000	1	8/1/95	12/30/95	
CS-AR94-07	2	Data collection	16,000	16,000	2	11/1/95	9/30/96	
CS-AR94-07	3	Data evaluation	16,000	16,000	3	2/1/96	12/30/96	63,000
CS-AR94-07	4	Scientific review	16,000	16,000	4	5/1/96		
CS-AR94-07	5	Draft study	16,000	16,000	5	8/1/96		
CS-AR94-07	6	Final report/study	16,000	16,000	6	11/1/96		
CS-AR94-07 Total			100,000	100,000				63,000
CS-AR94-08		Program Management CALSTART	369,000					369,000
CS-AR94-08 Total			369,000	0				369,000
CS-AR94-12	1	Feasibility Study	16,271		1	09/30/95	09/30/95	16,271
CS-AR94-12	2	Schematic/Housing for keyboard/display	10,000		2	12/31/95	12/31/95	9,957
CS-AR94-12	3	Establish internet connection	20,608		3	03/30/96	03/30/96	20,608
CS-AR94-12	4	Hardware Test Box for Analog/digital boards	54,077		4	06/30/96	06/30/96	54,077
CS-AR94-12	5	DC Converter Schematics. Build Prototype	16,666		5	09/30/96	09/30/96	21,700
CS-AR94-12	6	Second PCB. Testing CDAS & Installation	32,378		6	12/31/96	12/31/96	27,387
CS-AR94-12	7	Testing complete			7	03/30/97	03/30/97	
CS-AR94-12	8	Final report			8	06/30/97	06/30/97	
CS-AR94-12 Total			150,000	0				150,000

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR94-13		DELCO/Hughes Energy Mgmt Cont	18,000					18,000
CS-AR94-13 Total			18,000	**0**				18,000
CS-AR94-91		Re-allocated in Mod 12 to Mod 4 Moller	30,505					
CS-AR94-91 Total			30,505	**0**				**0**
CS-AR94-92		Re-allocated in Mod 12 to Mod 8 Trinity PM	53,000					
CS-AR94-92 Total			53,000	**0**				**0**
CS-AR94-93		Re-allocated in Mod 11	90,000					
CS-AR94-93 Total			90,000	**0**				**0**
CS-AR94-94		Re-allocated in Mod 12 to Mod 12	1,196,927					
CS-AR94-94 Total			1,196,927	**0**				**0**
ıtal			**3,504,000**	**5,210,266**				**2,064,818**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR94-09		Hatchery North	150,000	135,000				150,000
CS-AR94-09 Total			150,000	135,000				150,000
CS-AR94-10		NAS Planning	250,000					250,000
CS-AR94-10 Total			250,000	0				250,000
otal			**400,000**	135,000				**400,000**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR95-01	1	Computer model, Rotordynamic Analysis,	37,706	37,706	1	9/30/96	10/15/96	37,706
CS-AR95-01	2	Complete rotordynamic analysis	16,220	16,220	2	12/31/96	12/31/96	16,220
CS-AR95-01	3	Complete Test Plan, begin fabrication of test	10,160	8,470	3	3/30/97		36,276
CS-AR95-01	4	Complete fabrication of test rig	15,160	8,600	4	6/30/97		
CS-AR95-01	5	Fabricate standard bearing	12,182	23,618	5	9/30/97		
CS-AR95-01	6	Test Standard Bearing	10,124	8,600	6	12/31/97		
CS-AR95-01	7	Test Optimized bearing, Iterate computer	3,797	12,800	7	3/31/98		
CS-AR95-01	8	Final report	21,000	10,335	8	6/30/98		36,147
CS-AR95-01 Total			126,349	126,349				126,349
CS-AR95-02	1	Detail plan		900,000	1	7/7/96		
CS-AR95-02	2	Fabricate flywheels	230,000	300,000	2	9/7/96	7/16/96	195,200
CS-AR95-02	3	Design, prog. & fabricate DAS	90,000	140,000	3	9/7/96	12/2/96	171,057
CS-AR95-02	4	Design/Install containment chambers	50,000	80,000	4	9/7/96	12/30/96	
CS-AR95-02	5	Install modules/check system		60,000	5	10/7/96		
CS-AR95-02	6	Cycle tests/statistical analysis	20,000	80,000	6	3/7/97		
CS-AR95-02	7	Final report	10,000	40,000	7	6/7/97		
CS-AR95-02 Total			400,000	1,600,000				366,257
CS-AR95-03	1	Final draft of electrical test station design	5,307	5,400	1	TBD		
CS-AR95-03	2	Select mechanical design team. Complete design.	33,708	34,292	2	TBD		
CS-AR95-03	3	Design modifications to circuit breaker. Construct/debug test station. Fabricate circuit brekaer components.	30,238	30,762	3	TBD		
CS-AR95-03	4	Test guillotine circuit breakers.	19,217	20,171	4	TBD		
CS-AR95-03	5	Final guillotine circuit breaker design.	11,530	9,375	5	TBD		
CS-AR95-03 Total			100,000	100,000				0
CS-AR95-04	1	Alturdyne bus demonstration	65,000		1			58,500
CS-AR95-04 Total			65,000	0				58,500

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR95-05	1	Containment ring design	50,000	552,000	1	12/31/96	12/31/96	63,472
CS-AR95-05	2	Containment ring fabrication	75,000	77,000	2	3/30/97		97,463
CS-AR95-05	3	Assembly checkout/test	100,000	77,000	3	6/30/97		12,221
CS-AR95-05	4	Final report	34,500	77,000	4	9/30/96		4,169
CS-AR95-05 Total			259,500	783,000				177,325
CS-AR95-06A	1	Initiate work	75,000		1	4/1/96		75,000
CS-AR95-06A	2	Suspension/Differential Dev	60,287		2	4/30/96		13,881
CS-AR95-06A	3	Design review	60,287		3	6/30/96		59,688
CS-AR95-06A	4	4 Suspension design	60,287		4	9/30/96		75,894
CS-AR95-06A	5	5 Final report	60,288		6	2/28/97		91,686
CS-AR95-06A Total			316,149	0				316,149
CS-AR95-06B	1	Battery Mgmt Final report; Inverter repkg	309,974	53,972	1	9/31/96	9/31/96	309,974
CS-AR95-06B	2	DC-DC Converter Design; cell specs rpt; 2	215,495	37,520	2	12/31/96	12/31/96	215,490
CS-AR95-06B	3	Fianl report	58,385		3			0
CS-AR95-06B Total			583,854	91,492				525,464

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR95-07	1	Complete design	40,000	108,320	1	3/6/96		40,000
CS-AR95-07	2	Order batteries/tooling	57,855		2	3/30/96	5/31/96	53,162
CS-AR95-07	3	Finish block fabrication	25,000	46,500	3	5/15/96		38,490
CS-AR95-07	4	Receive/Evaluate Geo Metro	16,495		4	8/16/96		46,201
CS-AR95-07	5	Drivetrain/Engine Installation	37,500	37,500	5	10/4/96	12/30/96	22,489
CS-AR95-07	6	Vehicle testing	15,000	15,000	6	12/15/96		
CS-AR95-07	7	Final report and additional funds	10,000	10,000	7	2/4/97		
CS-AR95-07	8	Re-allocation	30,505					
CS-AR95-07 Total			232,355	217,320				200,342
CS-AR95-98		Re-allocation	-30,505					
CS-AR95-08 Total			-30,505					
CS-AR95-99		Program Management CALSTART	203,394					203,394
CS-AR95-99 Total			203,394	0				203,394
otal			2,256,096	2,918,161				**1,973,780**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR96-02	1	Initiate work	20,000			10/25/96		20,000
CS-AR96-02	2	Design of Major Components	34,573	44,113	1	12/31/96	12/31/96	34,573
CS-AR96-02	3	Prototype drawings complete	55,000	60,000	2	3/31/97	3/31/97	53,076
CS-AR96-02	4	Production of major components	50,000	45,000	3	6/30/97		50,000
CS-AR96-02	5	Prototype bench testing	17,000	21,000	4	9/30/97		17,000
CS-AR96-02	6	Production/Testing prototypes	35,000	8,000	5	12/31/97		29,242
CS-AR96-02	8	Final report	23,427	11,887	7	3/31/98		
CS-AR96-02 Total			235,000	190,000				203,891
CS-AR96-04		EV Manufacturability Canceled						
CS-AR96-04 Total			0	0				**0**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR96-05	1	Drive system design approved. System	30,000	96,700	1	1/10/97	1/10/97	30,000
CS-AR96-05	2	System controller modules design.	35,000	100,000	2	4/10/97	3/30/97	35,000
CS-AR96-05	3	Vehicle integration plan complete	35,000	75,000	3	7/10/97	3/30/97	35,000
CS-AR96-05	4	Major components integrated	30,000	50,000	4	10/10/97		30,000
CS-AR96-05	5	Vehicle fully integrated/testing initiated	30,000	75,000	5	1/10/98		30,000
CS-AR96-05	6	Phase 1 Operational testing complete	30,000	50,000	6	4/10/98		11,276
CS-AR96-05	7	Commercialization plan initiated	30,000	25,000	7	7/10/98		30,000
CS-AR96-05	8	Phase 2 testing complete/Business plan	5,000	25,000	8	10/10/98		
CS-AR96-05	9	Final report	25,000		9	1/10/99		
CS-AR96-05 Total			250,000	496,700				201,276
CS-AR96-06	1	Design study complete	51,000	57,000	1	1/10/97	2/21/97	51,000
CS-AR96-06	2	Prototype charging system constructed	72,000	53,000	2	4/10/97		72,000
CS-AR96-06	3	Moller engine delivered	22,000	25,000	3	7/10/97		30,000
CS-AR96-06	4	Integration complete	8,000	11,000	4	10/10/97		
CS-AR96-06	5	Testing complete	8,000	15,000	5	1/10/98		
CS-AR96-06	6	Final report	9,000	9,000	6	4/10/98		17,000
CS-AR96-06 Total			170,000	170,000				170,000

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR96-07	1	Design analysis against FMVSS & SAE	80,000	180,000	1			
CS-AR96-07	2	Complete door-re-engineering/prototypes	40,000	95,000	2			
CS-AR96-07	3	FMSS door side impact test. Release door for manufacturing	15,000	40,000	3			
CS-AR96-07	4	4 US Suppliers components list. FMVSS	15,000	35,000	4			
CS-AR96-07 Total			150,000	350,000				0
CS-AR96-08	5	Bluebird Buses equipped; Field data	200,000	108,000	5	6/30/97		
CS-AR96-08	6	Final report	50,000	15,000	6	9/30/97		
CS-AR96-08 Total			250,000	123,000				**0**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR96-09A	1	Quarterly report; battery selection	69,282		1	12/31/96	12/31/96	68,424
CS-AR96-09A	2	Transmission analysis	72,727		2	3/30/97		13,113
CS-AR96-09A	3	Battery Progress report	92,727		3	6/30/97		2,698
CS-AR96-09A	4	1-2 speed trans report	74,066		4	9/30/97		
CS-AR96-09A	5	Battery test report	50,910		5	12/31/97		
CS-AR96-09A Total			359,712	**0**				84,235
CS-AR96-09B	1	Initiate work	38,614		1	9/30/96	9/30/96	38,614
CS-AR96-09B	2	Test platform support	38,615		2	12/31/96	12/31/96	8,361
CS-AR96-09B	3	ADC fabrication	38,615		3	3/30/97		42,962
CS-AR96-09B	4	ADC testing	38,615	10,000	4	6/30/97		18,505
CS-AR96-09B	5	ADC integrated JTEV	38,615	10,000	5	9/30/97		24,154
CS-AR96-09B	6	Algorithms refined	38,615	10,000	6	12/31/97		
CS-AR96-09B	7	Test complete/Final report	38,615	6,000	7	3/30/98		
CS-AR96-09B Total			270,304	36,000				132,596
CS-AR96-10	1	Program Management CALSTART	188,502					140,983
CS-AR96-10 Total			188,502	**0**				140,983
CS-AR96-96	1	Proposals Pending	200,000					
CS-AR96-96 Total			200,000	**0**				0
)tal			2,073,518	**1,365,700**				**932,981**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR96-01	0	Initiate work	64,085	7,200		1/30/97	1/30/97	64,085
CS-AR96-01	1	Flywheel/Interface/FESS/LIU Specifications	119,298	45,600	1	3/30/97		45,600
CS-AR96-01	2	Design review/initial testing	116,791	88,400	2	6/30/97		88,400
CS-AR96-01	3	Manufacture/Phase 1 testing	37,895	320,146	3	9/30/97		67,634
CS-AR96-01	4	Installation drawings/program review	137,618	28,800	4	12/31/97		31,455
CS-AR96-01	5	Integration and inital check-out		33,900	5	3/30/98		
CS-AR96-01	6	Final report	77,401	32,550	6	6/30/98		
CS-AR96-01 Total			553,088	556,596				297,174
CS-AR96-99	1	Program Management CALSTART	53,000	0				15,000
CS-AR96-99		Re-allocation	-53,000					
CS-AR96-99 Total			0	0				15,000
Total			553,088	556,596				**312,174**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR97-01	1	AV	100,920	0				
CS-AR97-01 Total			100,920	0				0
CS-AR97-02	1	AV	76,276	0				
CS-AR97-02 Total			76,276	0				0
CS-AR97-03	1	RMSV	41,000	32,000				
CS-AR97-03 Total			41,000	32,000				0
CS-AR97-04	1	Conceptual Design	100,000	65,000				
CS-AR97-04	2	Detailed design	115,000	100,000				
CS-AR97-04	3	Manufacturing	130,000	125,000				
CS-AR97-04	4	Assembly and checkout	100,000	180,000				
CS-AR97-04	5	Testing/Final Report	50,000	100,000				
CS-AR97-04 Total			495,000	570,000				0
CS-AR97-05	1	Test data collection	45,000	45,000				45,000
CS-AR97-05	2	Establish test parameters and profile	33,000	52,000				52,000
CS-AR97-05	3	Report on designs/fabrication	5,000	10,000				
CS-AR97-05	4	Shock testing. Design/fab mounting system	280,000	255,000				17,243
CS-AR97-05	5	Prepare for testing	5,000	10,000				
CS-AR97-05	6	Testing at Aberdeen	82,000	78,000				
CS-AR97-05 Total			450,000	450,000				114,243

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR97-06	1	Capstone - Canceled	302,000	784,750				
CS-AR97-06 Total			302,000	784,750				0
CS-AR97-07	1	System Requirements	31,790	178,388	1	9/30/97		
CS-AR97-07	2	Charger Fabrication	58,582	328,730	2	12/31/97		
CS-AR97-07	3	Charger Test/CP/CV Fabrication	94,681	531,300	3	3/31/98		
CS-AR97-07	4	Installation of hardware/software	119,815	672,388	4	6/30/98		
CS-AR97-07	5	Charger Installed	28,540	160,149	5	9/30/98		
CS-AR97-07	6	Charger system Test	26,549	149,243	6	12/31/98		
CS-AR97-07	7	Analysis/Test results/Final report	40,043	72,352	7	2/1/99		
CS-AR97-07 Total			400,000	2,092,550				0
CS-AR97-08	1	Prepare for testing/heat study	17,500	17,500				
CS-AR97-08	2	Turbine/Motor results	12,500	12,500				
CS-AR97-08	3	Design/Final Report	20,000	20,000				
CS-AR97-08 Total			50,000	50,000				0
CS-AR97-09	1	Acquire/adapt computer codes	30,000	30,000				17,665
CS-AR97-09	2	Evaluation/Derive improved heat exchanger	40,000	44,000				
CS-AR97-09	3	Detailed design	40,000	42,000				
CS-AR97-09	4	Final Report	15,000	9,000				
CS-AR97-09 Total			125,000	125,000				17,665
CS-AR97-10	1	Foothill	200,000	455,000				
CS-AR97-10 Total			200,000	455,000				0
CS-AR97-11	1	Avcon	75,000	75,000				
CS-AR97-11 Total			75,000	75,000				0
CS-AR97-12	1	Compilation of existing data/Update EHVTP database	40,000					40,000
CS-AR97-12	2	Analysis of technology transfer to military applications	20,000					
CS-AR97-12	3	Evaluation of competing technologies	25,000					
CS-AR97-12	4	Assessment of market development factors	55,000					
CS-AR97-12	5	Final report	41,829					
CS-AR97-12 Total			181,829	**0**				40,000
CS-AR97-14	1	Database/Interface Design	5,779					
CS-AR97-14	2	Database/Interface creation	8,529					
CS-AR97-14	3	Data collection/coordination	7,282					
CS-AR97-14	4	Data collection/edit	13,214					
CS-AR97-14	5	Design graphic user interface	5,963					
CS-AR97-14	6	Integrate graphics	7,445					
CS-AR97-14	7	Check-off/post	7,966					
CS-AR97-14	8	Maintain/train	8,161					

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-AR97-14	9	Maintain/train. Final Report	5,661					17,500
CS-AR97-14 Total			70,000	**0**				17,500
CS-AR97-97		Re-allocation from Mod 7	(200,000)					
CS-AR97-97 Total			(200,000)	**0**				0
CS-AR97-98		Re-allocation from RA94	(1,196,927)					
CS-AR97-98 Total			(1,196,927)	**0**				0
CS-AR97-99		PROGRAM MANAGEMENT	256,700					35,000
CS-AR97-99 Total			256,700	**0**				35,000
›tal			1,426,798	**4,634,300**				**224,408**

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-DARO-02	1	TECE Thermo/Mech Assessment	300,000	100,000				50,000
CS-DARO-02	2	2/4 Stroke Concept Assessment	220,000	200,000				200,000
CS-DARO-02	3	2/4 Stroke Demo	480,000	700,000				
CS-DARO-02 Total			1,000,000	1,000,000				250,000
CS-DARO-03	1	1.0 Completion and submission of program plan	122,500	0				122,500
CS-DARO-03	2	1.1 Overall Engine Design, 1.2 Engine Thermal Cycle Analysis,1.1 Coordination of Analytical Effort with FEV, 2.1 ECA Fuel Injector Design,2.2 Fuel Injuector Options Assessment, 2.3 Coordinated Fuel Injection Review	122,500	245,000				122,500
CS-DARO-03 Total			245,000	245,000				245,000
CS-DARO-98		Re-allocation	-90,000					
CS-DARO-98		Program Management CALSTART	124,500					74,500
CS-DARO-98 Total			34,500	0				74,500
Total			1,279,500	1,245,000				569,500

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-DARO-01	1	Progress of sub-system testing, review of engine test facilities and plan for testing of advanced powerplant subsystem.	0	50,000				
CS-DARO-01	2	Powerplant integrated to existing dynamometer. Subsystem test complete.	0	75,000				
CS-DARO-01	3	Completion of low altitude simulation system. Completion of renovations. Commissioning of new propeller stand facility. Systems function - basic series. Systems optimization completed for baseline. Sea level mapping complete.	300,000	300,000				109,742
CS-DARO-01	4	Powerplant integrated to propeller test stand. Low altitude simulation mapping complete. Propstand limited durability demonstrated.	50,000	75,000				
CS-DARO-01	5	Continued Progress	50,000	0				
CS-DARO-01	6	Continued Progress	50,000	0				
CS-DARO-01	7	Demonstrated fuel injection durability maturation.	50,000	0				
CS-DARO-01 Total			500,000	500,000				109,742

Proj. No	Mile. No.	PROJECT TITLE AND NUMBER	DARPA	MATCHING	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
CS-DARO-04	1	Upgrade CALSTART web server	30,000					45,000
CS-DARO-04	2	Expand Vehicle Catalog	20,000					
CS-DARO-04	3	Develop component catalog	20,000					
CS-DARO-04	4	Develop AT Industry FAQ	20,000					
CS-DARO-04 Total			90,000	0				45,000
CS-DARO-99		Program Management CALSTART	50,000					15,000

Defense Advanced Research Projects Agency
Cooperative Agreement MDA972-95-2-0011
and modifications through P00012
Quarterly Report
January 1 to March 31, 1998

APPENDIX

A C PROPULSION
FINAL REPORT

CALSTART/DARPA

Electric Vehicle Research and Development Program

Grant # MDA972-95-2-0011

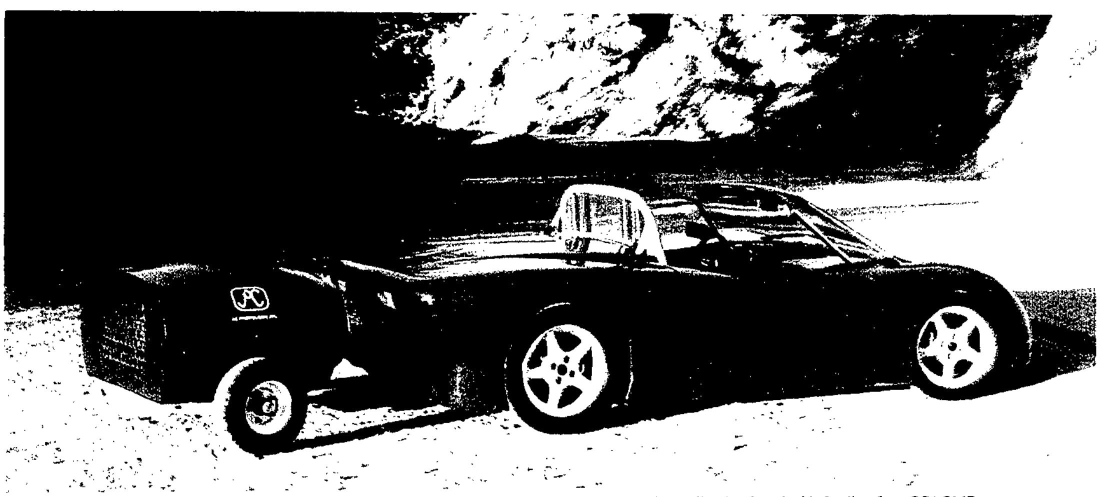
ELECTRIC VEHICLE RANGE EXTENDING GENERATOR

Development and Demonstration Project

Nov. 1996 - Dec. 1997

FINAL REPORT

March 5, 1998



Commercial application of range extending generator: AC Propulsion tzero towing range extending trailer developed with funding from SCAQMD

Submitted by
AC Propulsion, Inc.
San Dimas, CA

CONTENTS

EXECUTIVE SUMMARY

Objectives One of the major shortcomings of electric vehicles (EVs) is the limited range available on a single battery charge. A solution that allows EVs to sometimes drive extended distances, or operate away from charging infrastructure, is the use of an engine-powered generator-set that enables an electric vehicle to operate in hybrid mode. A properly designed generator-set can be integrated into the EV itself, or be towed behind the EV, in order to sustain battery charge over long distances and provide recharging power at remote locations. To date, available generators have not provided a satisfactory combination of size, weight, output, and cost to meet the demands of vehicular applications.

To meet the potential need for a vehicular traction charging system, CALSTART and AC Propulsion established objectives to develop an electric vehicle range extending generator to the specifications below.

- 20 kW output continuous @ 300 - 390 volts with 5000 rpm input speed
- total charging system weight of 35 kg.
- charging priority control for compatibility with regenerative braking
- design adaptability to other battery voltages, power levels, and input speeds

An additional objective was to demonstrate the charging system in operation coupled to a high specific output thermal engine. A Moller rotary engine was selected for the demonstration based on its potential for high output and small size.

Work Performed AC Propulsion has completed the five tasks specified in the CALSTART program participation agreement related to the design, development, and demonstration of the charging system.

Task 1 – Design of Alternator and Charging Control System

Using the design techniques pioneered in its electric vehicle drive systems, AC Propulsion designed an alternator and charging control system to meet project objectives.

Task 2 – Construction of Prototype Alternator and Control System

AC Propulsion constructed a prototype charging system based on the design developed in Task 1 using proprietary manufacturing techniques proven in its high output electric vehicle drive systems.

Task 3 – Test and Development of Prototype Charging System

The prototype charging system was developed and tested using AC Propulsion's in-house electric dynamometer and test facilities.

Task 4 – Integration of Charging System and Moller Engine

The charging system was mated to a Moller rotary engine using a toothed-belt drive. The integrated power system was mounted on a test stand with representative cooling, air, fuel, and exhaust systems

Task 5 – Test and Development of Integrated Power System

AC Propulsion tested the integrated power system for output, and thermal, electrical and overall efficiency using resistive loads to dissipate the electrical power.

Results In dyno testing, the charging system met or exceeded all project objectives. Continuous output of 20 kW at 300 - 390 volts is achieved at 7000 rpm. Alternator efficiency is 91%. Alternator weight is 25 kg (55 lb).

The alternator controller employs self-excitation with capacitors for phase shifting, resulting in a simple, robust, and low cost design that achieves direct control of output with engine speed. Controller weight is 3 kg (6.5 lb). Total package size of the charging system is 15 liter (0.53 cu ft). These characteristics yield specific output of 0.71 kW/kg (0.33 kW/lb) and power density of 1.3 kW/liter (38 kW/cu ft).

The charging system was adapted to the Moller rotary engine for demonstration as a complete power unit. A toothed-belt drive allowed a compact mounting arrangement that matched the Moller engine's recommended 5000 rpm operating point to the alternator's 7000 rpm design speed. In operational testing, the belt-drive worked well, and drive-related losses were acceptable. Characteristics of the Moller engine determine overall performance of the generator-set. At wide-open-throttle, maximum system output is 14.5 kW DC at engine speed of 4800 rpm. At that operating point, specific fuel consumption is 0.72 kg/kWh (0.26 gal/kWh).

Outlook The charging system developed for this project provides high specific output and high power density, both of which are essential for resolving the component packaging challenges inherent in hybrid-vehicle design. At 20 kW, the output of this development unit is sized for the road-load requirements of compact-size passenger cars. The alternator design and control methodology, however, are adaptable to units of 10 to 50 kW or higher.

The level of performance delivered by the Moller engine does not meet the requirements of the hybrid or range extender applications. Power and efficiency are too low, and its current configuration is not well suited to direct-drive systems. Other thermal engines can be adapted more readily to provide the levels of performance required for specific applications.

No follow-on work is planned as a continuation of this project. The charging system technology developed during the course of this project is ready for commercialization. AC Propulsion plans to market the charging system both as a stand-alone product with application to hybrid-electric drive systems, and as part of a range extending trailer to be towed behind EVs for long distance travel.

FINAL REPORT

BACKGROUND

One of the major shortcomings of electric vehicles (EVs) is the limited range available on a single battery charge. For EVs that must sometimes drive extended distances, or operate away from charging infrastructure, one solution is the use of an engine-powered generator-set that allows an electric vehicle to operate in hybrid mode. A properly designed generator-set can be integrated into the EV itself, or be towed behind the EV, in order to sustain battery charge over long distances and provide recharging power at remote locations. To date, available generators have not provided a satisfactory combination of size, weight, output, and cost to meet the demands of vehicular applications. Necessary characteristics include the following:

- Charging output matched to the EV road load and battery voltage requirements
- High specific output to reduce package size and weight.
- Robust simplicity for durability and reliability
- Convenience and low cost that will provide a marketable alternative to using a conventional vehicle for long trips.

With DARPA funding, CALSTART, contracted AC Propulsion Inc.(AC Propulsion) to develop a charging system specifically for electric vehicle range extending generators (RXGs) for hybrid-vehicle application. Since 1994, AC Propulsion has developed high output RXGs and used them in its EV powertrain testing programs. Mounted on a trailer and towed behind an EV, these units allow rapid accumulation of test mileage by eliminating the need to stop for battery recharging. AC Propulsion and some of its customers have accumulated tens of thousands of EV test miles using these prototype range extending trailers.

For expedience, alternators used by AC Propulsion in RXG trailers had been built from aircraft units modified to operate at the speeds and voltages required for EV charging. These units are extremely well built, but are prohibitively expensive, reflecting the special reliability requirements of aircraft applications. Commercialization of RXGs requires an alternator and control system that is better suited to the specific requirements of RXG use. Although automakers are actively pursuing development of hybrid vehicles, and these all require some kind of high output generator for charging, no charging systems that are well-suited for the RXG application are available off-the-shelf.

The primary purpose of the work performed for this project was to design, develop, and test an efficient, high specific output charging system dedicated to onboard or trailer-mounted RXG applications. The benefits of such a design will include optimized operational characteristics, potential for lower cost in volume production, and adaptability of output to match voltage and power requirements of different EV designs.

Additionally, the work performed matched the newly developed charging system to the Moller advanced rotary engine. The Moller engine has promised the potential of high specific output, an important attribute for any RXG powerplant. The resulting generator-set demonstrated the charging system developed for this project as part of an integrated power system.

OBJECTIVES

AC Propulsion designs, develops, and manufactures high performance electric vehicle propulsion systems and produces EV conversions based on its electric drivetrains. AC Propulsion currently manufactures the AC-150 electric drivetrain, a 150 kW drive system including motor, final drive, and integrated control electronics including inverter, regeneration control, 20 kW charger, and 12v DC power supply. The 200 horsepower traction motor is 305 mm in diameter, 380 mm long and weighs 55 kg with cooling shroud and blower. The concept for this project was to apply the design and manufacturing techniques AC Propulsion has used to achieve the traction motor's exceptional level of power density to the similar but unique challenges of designing a charging system for an electric vehicle range extending generator.

AC Propulsion's experience with trailer-mounted RXGs has confirmed that such units can provide hybrid capability for pure EVs, but only if two conditions are met: 1) charger output is sufficient and 2) the output characteristic is matched to the battery requirements. If these conditions are not met, the promise of unconstrained driving range cannot be realized.

The power output must exceed the EV road load at the desired cruising speed in order to provide for charge recovery. Under various conditions such as hill climbing, the EV battery may be drawn below the optimum state of charge (SOC). The only way to recover the charge is to slow the vehicle to a speed where RXG output exceeds road load and use the excess output to charge the battery. If the RXG output is not high enough, the charge recovery speed will be too slow, and the EV will be unable to keep up with traffic. For efficient, small-to-medium size EVs, RXG output of 15 to 20 kW is necessary to provide comfortable freeway cruising.

The second critical condition is that the trailer must provide rated output over a wide range of charging voltages. To recover and maintain high state-of-charge at freeway speeds, the RXG power output cannot drop off as battery SOC and voltage increase. This necessary characteristic is shown as the solid line in Figure 1. The battery voltage varies widely depending on battery SOC, so the charger must be able to achieve its rated output at higher and higher voltages as the battery charges. AC Propulsion achieves this critical requirement in its range extenders by using active control of the alternator output. The result is a constant output charging characteristic that provides rated output almost up to 100% SOC. This characteristic is compared to the typical charger characteristic achieved with passive control, the dashed line, in Figure 1.

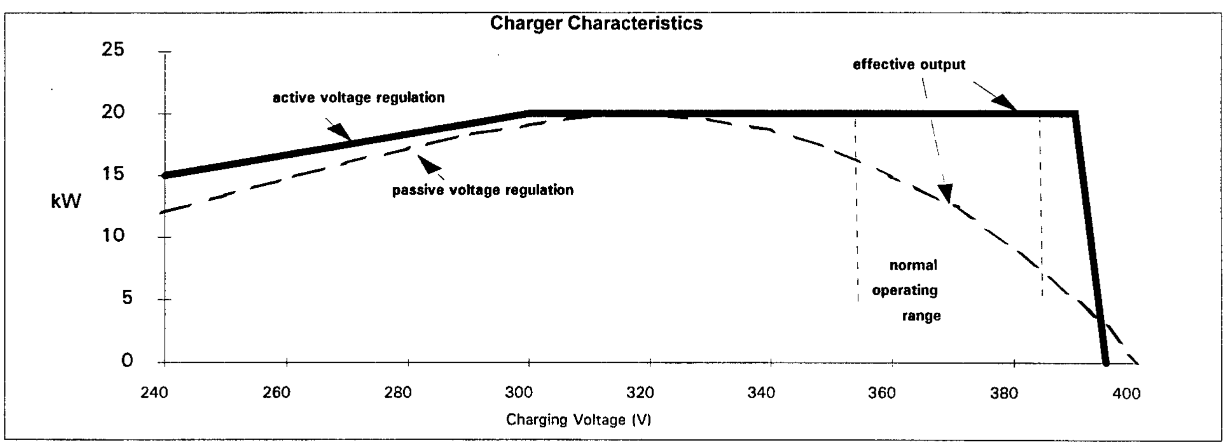


Figure 1 Desired output characteristic for range extending generator

Note that both chargers are rated at 20 kW output, but without active control, rated charging output is achieved only when the battery is in a highly discharged condition. During normal highway operation with battery voltage in the 360 V range, output without active control drops to about half of rated output, too low to sustain high SOC at highway speeds.

With active control of alternator output, the charger provides a broad region of constant power charging, the flat region of the output curve, and a very sharp high voltage cutoff to protect system electronics. Since it is desirable to maintain batteries near full charge to provide reserve power for hill climbing and passing, chargers without active control must be oversized to maintain full battery charge under normal cruise conditions. This conflicts with the requirements for small size and light weight.

The recognized requirements for high specific output, adequate power, and an appropriate charging characteristic, and the desire to demonstrate the charging system with a Moller rotary engine were integrated in the project design proposal described below.

Design Proposal

The motivation for producing an RXG is to provide hardware that can be used to develop hybrid drive systems that expand the utility of pure EVs. This objective requires that the RXG itself be designed with good potential for near term commercialization. Accordingly, AC Propulsion developed a design proposal to satisfy the needs of consumers, including output matched to driving needs, compact package size, and potential for low cost production.

Furthermore, the design proposal included AC propulsion's accumulated design priorities and experience, specifications provided for the Moller rotary engine, and DARPA's requirements for this development effort. The design proposal for RXG power system included the following specifications.

Charging System
- up to 20 kW output continuous @ 300 - 390 volts with 5000 rpm input speed
- constant current charging at low battery voltages
- charging priority control for compatibility with regenerative braking
- adaptability of the basic design to other battery voltages, power levels, and input speeds
- total charging system weight of 35 kg.

IC Engine
- 30 hp continuous @ 5000
- single rotor rotary
- water-cooled
- fuel injected
- onboard 12V starter

Engine Control
- drive of alternator via coupling to engine crankshaft
- remote starting with warmup idle and power modes
- automatic load control via throttle servo

WORK PERFORMED

The proposed course of work was structured in three phases comprising six tasks. In Phase 1, AC Propulsion performed Tasks 1 – 3, design, development, and test of the RXG charging system to the stated performance objectives.

Phase II, development of the integrated power system, was conducted by AC Propulsion and Moller International. In Task 4, Moller International delivered a rotary engine to AC Propulsion and the two units were integrated into a complete power system. In Task 5, the resulting power system was bench tested at AC Propulsion to determine operating characteristics.

In Phase III, AC Propulsion analyzed the test performance of the charging system and the generator set and prepared this final report of the development program.

Activity under the five development tasks is described below.

Task 1 - Design of Alternator and Charging Control System

Surveys of commercially available alternators did not identify any models well-suited for the range extender application. The requirements for high specific output and constant output over varying battery voltage rule-out typical generator-set hardware. Less conventional approaches such as the permanent magnet hybrid homopolar magnet alternator that offer high efficiency and compact design do not operate over a broad enough voltage range. Permanent magnet systems also incur higher inherent costs due to the cost penalty of rare-earth-based magnets.

A design concept for the range extending alternator was developed based on proprietary AC Propulsion construction and control techniques. Concept testing using a standard AC Propulsion traction motor operating as a generator demonstrated feasibility for the design concept which would result in a compact design with high efficiency and reduced control complexity.

Dynamometer testing confirmed the feasibility of using the architecture of the AC Propulsion traction motor. This motor, well-proven as a power unit for electric vehicles offers the advantages of simple and robust construction, high specific output, high efficiency, and air cooling, all desirable characteristics for the RXG application. In EV applications, the motor serves as a generator during regenerative braking, so its capability to generate power is established.

Although the traction motor itself is not optimized for the specific range extender application, use of the motor architecture allows generators of varying speeds and outputs to be developed by changing the length and field windings for different applications. The generators can share basic dimensions and components such as end plates, housing, rotor shaft (except for length), and laminations. By sharing these components, economies of scale and reduced costs can be approached more rapidly. Using the motor as a generator in the range extender application, required innovation in the control system in order to avoid the size and complexity of the inverter used to control motor/generator function in a traction motor application.

Based on prior knowledge and examples in the literature of the use of self-excitation of AC induction motors, and the use of switched capacitors for phase shifting, a laboratory control system was developed for feasibility testing on the dyno. The prototype control system used low-frequency zero-current switching of the capacitors at the synchronous frequency (typically a few hundred Hz), so component costs are limited and undesirable EMI is not generated. A starter circuit initiates field excitation at startup, but the field is self-exciting during operation.

An off-the-shelf AC Propulsion traction motor was used for the initial tests which demonstrated satisfactory levels of output, efficiency, and control authority to justify moving ahead with a design based on the self-excitation, switched-capacitor concept. Based on successful testing of the control concept, a prototype alternator and control system design effort was initiated.

Sizing studies established that if the target operating speed is 5000 rpm, the standard length AC-150 motor could be used for the alternator. It was thought that by using un-modified motor components where possible, the design and validation requirements would be reduced and manufacturing processes already proven. The prototype alternator would differ from the production motor primarily in its stator windings. The stator would be configured for operation under the self-excitation control concept, and to optimize efficiency at the design operating point.

Consistent with the program objectives of low design cost, small size, and light weight, the control system was designed to use off-the-shelf components in a compact and easy to manufacture package. This necessitated careful layout of the componentry considering both overall size and heat rejection requirements. A custom designed circuit board was developed to minimize wiring and improve reliability.

Midway through the charging system development program, two design changes were indicated based on the results of testing activities (see under Tasks 3 below). The design changes were 1) conversion from a four-pole to an eight-pole design, and 2) modification of the stator design to implement a more efficient and robust control scheme. The simpler control strategy continued to use capacitors for phase shifting, but eliminated the capacitor switching function entirely. Alternator output control is achieved directly from closed loop control of engine speed. The steep slope of the alternator output/speed curve allows full control of output over a very narrow speed range as shown in Figure 2.

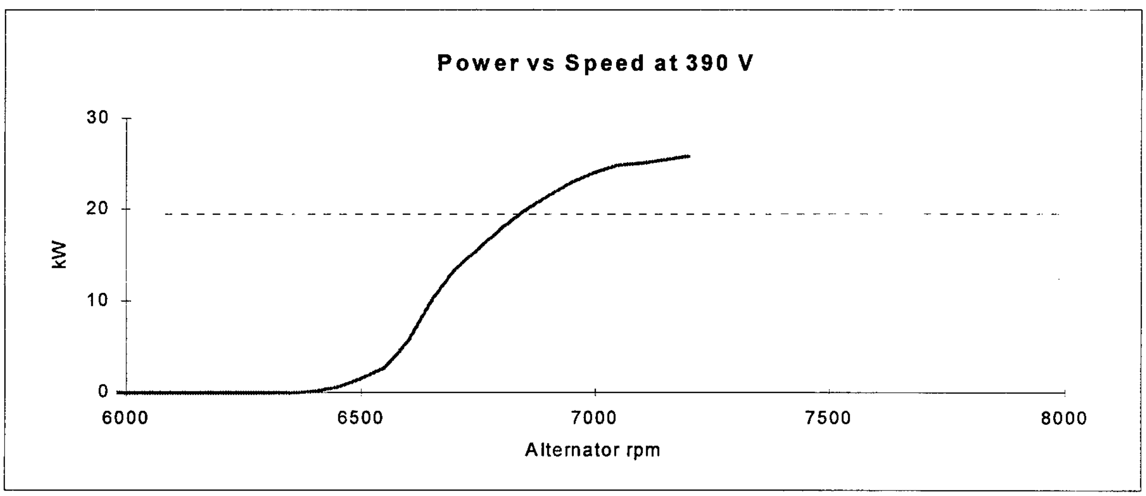


Figure 2 Charge system output vs speed characteristic

Upon receipt of the Moller engine, midway through the project, packaging studies led to the decision to change the alternator drive concept from direct, crankshaft drive to toothed-belt drive (see under Task 4 below). The necessity of using a belt drive created the opportunity to increase the alternator operating speed by varying pulley diameters. At higher operating speed, the alternator can be smaller for the same output. The conversion to belt-drive required two significant changes to the alternator design. First, it was made smaller in both length and diameter to achieve optimal efficiency at the new operating point. Second, the belt-drive required a re-design of the end-plate at the pulley-end to accommodate a bearing capable of withstanding the loads imposed by the belt.

These changes represented a major departure from the original plan to use a direct-driven, slightly modified traction motor as the alternator. With the conversion to belt drive, the ability to achieve high parts commonality with motors, and the desired economies of scale were lost. The redesigned alternator, however did preserve the proven architecture of the traction motor design, and by operating it at a higher speed, size and weight were reduced.

To improve packaging and reduce cost, a shaft-driven cooling fan design was adopted after testing for air flow and efficiency determined that a satisfactory design could be produced at reasonable cost. The shaft-mount fan replaced the variable-speed, side-mounted centrifugal blower used for traction motor applications. The fan mounts to the end of the motor shaft and runs at shaft speed, providing air to ductwork running the length of the motor. Since the alternator runs primarily at high load, the loss of control of cooling fan output, compared to the pulse-width-modulation controlled blower used with the traction motor, does not cause a significant loss in efficiency. End-mounting the fan also improved packaging by freeing the space occupied by the side-mounted blower.

Task 2 - Construction of Prototype Alternator and Control System

Concurrently with the design effort, sourcing of components for the prototype alternator construction began. Most of these components were sourced to the same suppliers who produce components for standard AC Propulsion drive systems.

The first prototype used identical construction techniques and components, including the main housing, end plates, mainshaft, rotor, stator, and cooling shroud , as the traction motor from the AC-150 drive system. As a proven design, this approach eliminated component design as a variable in the initial evaluation of alternator control systems.

A total of three traction-motor-based prototype alternators, with additional variations on each, were constructed during the course of development. For initial tests, the first prototype belt-drive alternator was then made from cut down traction motor rotor and shaft. The smaller diameter winding was fitted to a shortened traction motor housing using a spacer sleeve.

Once the higher speed operation was validated the first prototype 7000 rpm alternator was constructed. The smaller size resulted in a weight savings of 40 - 50 pounds over the original traction motor. Even with the added weight of the belt drive system, meaningful weight and size reductions were achieved with the higher-speed unit.

Compared with the original traction unit, the final alternator differs in length, diameter, drive configuration, and 8-pole vs 4-pole design. Despite these numerous changes, the final design maintains essentially similar architecture to the traction motor and can be produced with the same processes.

Task 3 - Test and development of charging system

Prior to completion of the first prototype alternator, a test alternator derived from an existing AC-150 motor and modified according to the requirements of the self-excitation control scheme, was dynamometer tested to confirm the potential performance of the design approach. At the test operating point, the alternator performed according to design. On the dyno, output of 20 kW was achieved between 300V and 390V. Operating efficiency of 90% was achieved in these early tests.

The high efficiency observed promises to help realize low fuel consumption of the range extending generator and reduces the cooling requirements of the generator itself, thus providing packaging and cost benefits.

The prototype control system was debugged and dyno tested with the first prototype alternator. The prototype charging system successfully completed a series of tests of output, efficiency, operating temperature, and over-voltage and over-current protections. Again, the target output of 20 kW was achieved with efficiency at 90 - 91%. All system protection circuits worked properly.

The system did not exhibit a temperature-related output loss that has been observed in modified aircraft alternators used in EV range extender service. Dyno testing did reveal a maximum winding temperature of 134° C after two hours of continuous operation. Although this temperature did not create any operational problems, a lower temperature was thought to be desirable. As a way to reduce winding temperature, the use of an eight-pole alternator design which trades iron losses for copper losses was investigated. A prototype eight-pole-wound alternator and control system was developed and tested. It operated at a winding temperature of 120° C with the same output and efficiency. An additional benefit of the eight-pole design is a weight reduction of at least 10 pounds. Although the eight-pole design diverges from the concept of building directly from the traction motor platform, the loss in commonality is justified by the temperature control and weight savings benefits.

A second eight-pole alternator with a simplified winding design was constructed for testing to determine the final alternator configuration. It successfully completed dyno testing at target power and efficiency levels. The eight-pole design was selected because of the advantages it offers in terms of cooler running as well as reduced weight.

Development testing revealed possible reliability problems with the alternator control system due to variability in capacitor switching relay specifications as delivered from suppliers. Efforts to eliminate the mechanism for the switching relay failures resulted instead in a modification to the control strategy that eliminates the need for capacitor switching at all. The revised system relies on closed-loop control of operating speed to regulate operating output. Full implementation of this control strategy required redesigned alternator components, but no other significant changes. The new control methodology results in a significant component cost reduction, and more robust control authority.

With the speed-based output control strategy, the prototype charging system again successfully completed dynamometer tests of output, efficiency, operating temperature, and over-voltage and over-current protections. The target output of 20 kW was achieved with efficiency at 90 - 91%. All system protection circuits worked properly.

A series of tests over a range of typical operating speeds and voltages yielded the results shown in Table 1. During all testing, including extended operation at full output, winding temperature remained below 120° C, an acceptable level for achieving good durability.

Table 1 Tested output and efficiency for range extending generator

Output Voltage (V)	Output Power (kW DC)	Alternator Speed (rpm)	Electrical Efficiency
300	18.9	7100	90.5%
330	20.3	6900	91.0%
360	21.2	6800	91.0%
390	21.4	6900	91.0%

The charging control system was designed to cut alternator output as voltage approaches a specified threshold. In order to accommodate the rapid voltage rises associated with high regenerative braking power and to protect he batteries from voltage spikes, rapid response was built into the control system. The output characteristic of this charging system facilitates the necessary response because the steep power vs speed profiles shown in Figure 3 enable the full range of output control for both constant voltage and constant power operation to be achieved over a narrow range of operating speeds.

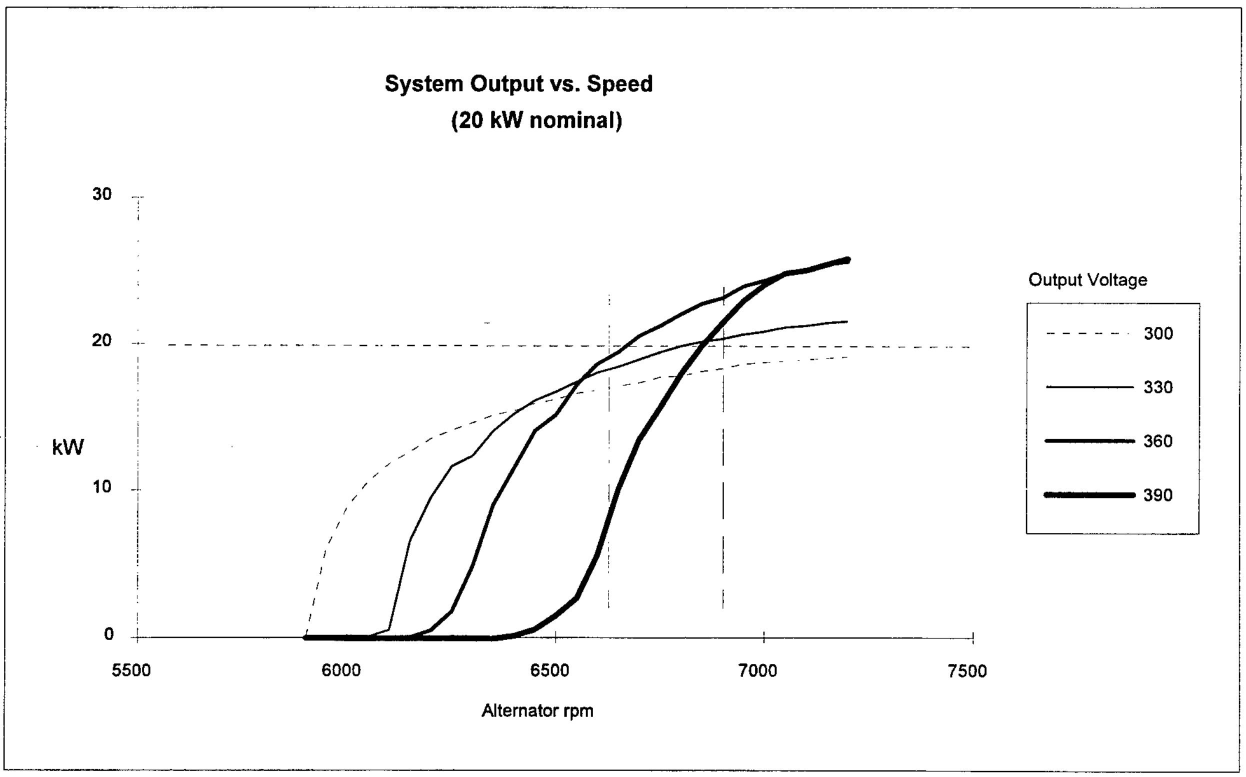


Figure 3 Output curves show complete output control can be achieved over a narrow rpm range

Task 4 - Integration of Charging System and Moller Engine

Moller International, Davis, California, was commissioned to deliver a rotary engine to serve as the power plant for an integrated power system using the charging system developed under Phase 1. The engine was ordered to the following specifications:

- Single chamber air-cooled rotary engine
- Electronic fuel injection system adaptable to AC Propulsion automatic load control
- Onboard 12 V starter
- Capable of sustained operation at 30 hp @ 5000 rpm
- Engine to be in running condition as delivered

Although we had originally proposed the use of a water-cooled engine, Moller, recommended the use of an air-cooled version which required less lead time and simplified design of the test stand yet could still demonstrate the functionality of the range extending generator. Moller will be able to provide water-cooled engines in the future if required for specific applications.

The Moller engine was received June 27, 1997. Prior to delivery, the engine was fitted with electronic fuel injection and calibrated on a dynamometer for operation at the specified load and speed by Moller. Dyno tests at Moller revealed that engine cooling on the test stand may require auxiliary fans to control temperature during demonstrations.

Upon delivery of the Moller engine, an obstacle to the planned close-coupled mounting of the alternator became apparent. The Moller engine has no bell-housing or provision for mounting any kind of output device to the engine structure. The flywheel diameter is larger than the engine itself, so attachment of a bell-housing adapter to the engine would be difficult without extensive modification to the basic engine castings. Any such an adapter would possibly obstruct the flow path for the cooling air.

The engine and alternator could both be mounted to a single external frame, but without the ability to mate the alternator directly to the engine block, the mounting would not be rigid enough to hold the alignment tolerances required for close-coupled mounting of the alternator to the engine. This meant that close-coupled mounting was not possible. For any in-line mounting, an intermediate shaft with some compliance for misalignment would be required.

An alternative was to mount the alternator adjacent to the engine with shafts parallel, and drive it with a belt. This approach would result in a package as compact as the close-coupled configuration originally planned. The drive losses through the belt would reduce efficiency somewhat, but the opportunity to drive the alternator at a higher speed by varying pulley diameters would allow the use of a smaller and lighter alternator. The belt-drive approach was selected because it offered superior package characteristics compared to in-line mounting.

AC Propulsion designed a belt-drive using a 30 mm-wide, 8 mm-pitch drive-belt and commercially available drive-belt pulleys. Pulley sizes of 64-tooth for the drive pulley and 44-tooth for the driven pulley achieved the proper speed ratio between the engine and alternator and kept belt surface speed at an acceptable level. The drive pulley was mounted directly to the face of the existing flywheel to reduce the overhang of the drive belt tension load.

In order to feed the alternator mounting loads into the engine structure without distorting or over stressing the engine, a mounting plate designed to pick up six of the engine clamping bolts was fabricated from 0.40" thick aluminum. To this plate were attached the alternator mounting bosses that determined the correct alignment between the alternator and engine, and allowed the alternator to pivot to tension the drive belt. A second structural plate of 0.25" aluminum mounted to the fan and air duct housing provided added rigidity by taking the moments developed by the drive-belt tension.

The original alternator design assumed direct drive via coupling from the engine. In order to accommodate the side loads generated by the change to a belt drive system, the drive-end end plate was re-sized to accept a larger bearing. Both alternator endplates included mounting ears to attach to the engine bracket. The alternator shaft was redesigned to provide space for mounting the toothed belt pulley.

As completed, the belt-drive provided a way to use the Moller engine in a power system application without requiring extensive modifications to the engine itself, and achieved compact mounting of the alternator. A rotary engine designed for the RXG application could include engine structure for direct drive or belt drive with little if any cost penalty. A water-cooled version of the of the Moller engine is said to be under development and this would facilitate design of a more substantial engine structure by eliminating the need for high volume air flow for cooling.

Task 5 - Test and Development of Integrated Power System

For testing and demonstration purposes, the AC Propulsion alternator/Moller engine power system was mounted to a test stand. The stand accommodated laboratory fuel and exhaust systems. A resistive load with adjustable voltage and current control was used to simulate the traction battery and to dissipate the electric power generated.

The alternator, engine, fuel system and exhaust system were instrumented for monitoring and collecting power system operational data. Instrumentation included the following:

- Exhaust gas oxygen sensor
- Output voltage and current
- Gravimetric fuel flow
- Exhaust back pressure
- Engine speed
- Engie block, and cooling air temperature

In its first bench test, the power system started and ran. The belt drive required some adjustment to achieve proper alignment and tension, but was trouble-free thereafter.

The Moller fuel control system proved to be incompatible with the alternator control system due to the rapid transients required for automatic alternator output control. The fuel system could not track rapid throttle excursions without backfires or die-outs. This was a particular problem for startups when the alternator loads the engine quite suddenly. In order to obtain steady-state test data, manual control was used for all bench tests of the integrated power system. Operating results from the bench test demonstration are shown in Table 2.

Table 2 Results of range extending generator demonstration test

Measured Values	
Engine speed	4800 rpm
Output voltage	382 V
Output current	39.1 A
EGO sensor output	0.7 V
Exhaust backpressure	1.5 psi
Fuel consumption	2.9 gm/sec
Calculated Values	
Output power (kW)	14.9 kW
Specific fuel consumption	0.72 kg/kWh

As shown, at the tested engine speed of 4800 rpm, wide-open-throttle operation produced electrical output of only 14.9 kW DC, compared to the 20 kW capability of the alternator. The engine did not have sufficient power to drive the alternator to its maximum output. Considering total losses in the charging system, engine output of no more than 23 hp was available. Discussions with Moller International indicated that higher output could be achieved at higher rpm, although rotor tip seal life deteriorates as speed increases. The fuel system calibration did not provide for higher speed operation so no test runs were made at higher rpm. At the observed maximum output level, engine temperature control required a large auxiliary air blower to augment the flow of the integral engine cooling fan.

Fuel consumption was higher than anticipated. Although the fuel injection calibration provided by Moller was fixed, adjustment to the throttle control linkage provided some control over air-fuel ratio. In efforts to optimize fuel efficiency the linkage was varied over its range of adjustment. Over that operating range, output from the O2 sensor indicated that the engine was operating near stoichiometry. The range of air-fuel ratio adjustment provided little variation in power or fuel consumption, suggesting that the fuel calibration was not the cause of high fuel consumption. Exhaust back-pressure was 1.5 psi, a reasonable value that would not cause excessive fuel consumption.

RESULTS

As the participant with CALSTART in the Electric Vehicle Range Extending Generator project, AC Propulsion designed, built, tested, and demonstrated a vehicular traction charging system well-suited for adaptation to hybrid electric vehicle applications. The purpose-designed charging system meets or exceeds the operating objectives established at project initiation for weight, power, output characteristics, and commercial potential as shown below.

- Power output of 20 kW DC continuous @ 300 - 390 volts
- Electrical efficiency of 91%.

- Total charging system weight of 28 kg (62 lb).
- Total charging system size of 15 liter (0.53 cu ft).
- Rapid response output control to protect system electronics and provide compatibility with regenerative braking
- Design adaptability to other battery voltages, power levels, and input speeds

Charging system specific output of 0.71 kW/kg (0.33 kW/lb) and power density of 1.3 kW/liter (38 kW/cu ft) make it ideal for either range extending trailers for electric vehicles, or integrated hybrid electric vehicles where packaging and weight constraints limit the applicability of less compact designs. The design simplicity, low-cost AC-induction design, and robust control algorithm will offer advantages in terms of cost, reliability, durability, and maintainability.

An additional project objective, to demonstrate the charging system in operation coupled to a Moller rotary engine, was completed, but the output and fuel efficiency of the generator-set combination fell below expectations. At wide-open-throttle, maximum output was 14.9 kW DC at engine speed of 4800 rpm. The air-cooled Moller design could not sustain even this output without an auxiliary blower. Including the power to operate the blower would decrease net output and efficiency somewhat. The necessity for additional cooling power, precludes a meaningful calculation of power density for the generator-set combination.

The specific fuel consumption for the generator set combination, 0.72 kg/kWh, is high for this type of application. Commercial generator sets offer specific fuel consumption values in the range of 0.25 - 0.45 kg/kWh. Rotary engines are not noted for good fuel efficiency, but improvements over observed values should be possible. Optimization of fuel efficiency was not included in the scope of this project, and considerable development effort would be required to improve fuel consumption of the Moller engine to an acceptable value.

OUTLOOK

During the execution of work for this project, the commercial prospects for both pure electric vehicles, and for hybrid-electric vehicles expanded significantly. Although still lagging behind EVs in terms of commercial realization, HEVs have enjoyed great exposure in the form of concept vehicles, and automakers seem committed to introducing HEVs to the market.

Most HEVs from automakers use the parallel-hybrid design that relies on the thermal engine for some or most of the motive power and uses the electrical drive primarily for the recapture and use of braking energy. This is a logical approach because it represents an evolutionary departure from the type of drive system currently produced by automakers and accepted by the market.

The series-hybrid vehicle is the more radical departure from conventional vehicle design because it requires a fully capable electric drive system. As a result, it offers the advantage of being able to operate entirely on stored electrical energy for a significant distance, eliminating exhaust, noise, and thermal emissions while doing so. The series-hybrid represents the greater challenge from a packaging standpoint because it requires a much larger battery than the parallel hybrid. The necessity to package a high-output generator-set in what is essentially a pure EV requires that every component be designed with consideration for packaging constraints.

The charging system developed for this project provides high specific output and high power density, both of which are essential for resolving the component packaging challenges inherent in series-hybrid vehicle design. At 20 kW, the output of this development unit is sized for the road-load requirements of compact-size passenger cars. The alternator design and control methodology, however, are adaptable to units of 10 to 50 kW or higher.

The generator-set using the Moller engine demonstrated a compact and lightweight power unit. As noted, however, its performance fell short of requirements in both power and efficiency. Development of a thermal engine to power the alternator requires attention to specific output, specific fuel consumption, and application packaging requirements. The charging system developed here is intended to provide the design engineer with maximum adaptability and packaging flexibility to meet the difficult packaging requirements of series-hybrid vehicle design.

AC Propulsion plans to market the charging system developed during the course of this project. Two applications are evident, charging systems for series hybrid electric vehicles, and range extending trailers for pure electric vehicles. Series hybrid vehicles differ from parallel hybrids by offering useful range and performance on battery power only. This capability is critical for vehicles whose mission requires at least some operation without exhaust, thermal, or noise emissions. Industrial equipment, buses, and military vehicles, as well as passenger vehicles may find benefits from series-hybrid operation.

The other application for the charging system is the range extending trailer. AC Propulsion has constructed and tested a trailer using a 500cc motorcycle engine for power. The generator set combination produces 22 kW DC output with good fuel economy and low emissions. That power level can supply average road-load requirements for an efficient EV operating at 70 to 75 mph, and thus sustain battery charge indefinitely. Such performance makes all-day driving, by EV, practical, efficient, and convenient.

The range extending trailer concept represents a real stretch for traditional automakers, and for consumers too. Drivers who have accumulated considerable EV mileage, however, readily acknowledge the benefits of a detachable power system for long trips. Two major automakers have expressed interest in testing the trailer concept, and AC Propulsion plans demonstrations and additional development of range extending trailer technology.

APPENDIX - HARDWARE PHOTOGRAPHS

Photo 1 – The 20 kW, 7000 rpm alternator is an 8-pole, AC-induction design. It is air-cooled with an integral, shaft-mounted cooling fan. The alternator may be belt-driven, as shown here, or coupled directly to the output shaft of the drive engine. The design can be readily re-sized for operation at other speed or output ratings. This unit weighs 25 kg. Dimensions are 280 mm length, and 230 mm diameter.

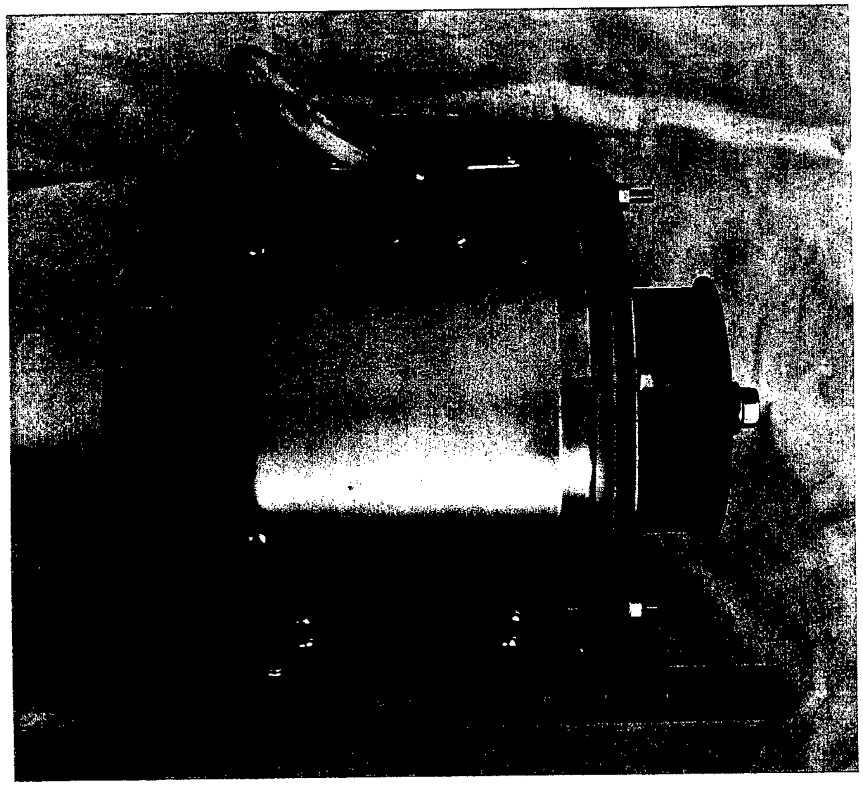


Photo 2 – The 20 kW control unit operates with self-excitation and uses capacitors (shown at right)for phase shifting. The simple control strategy using low-cost componentry keeps the controller small (255 x 185 x 107 mm) and light (3 kg).

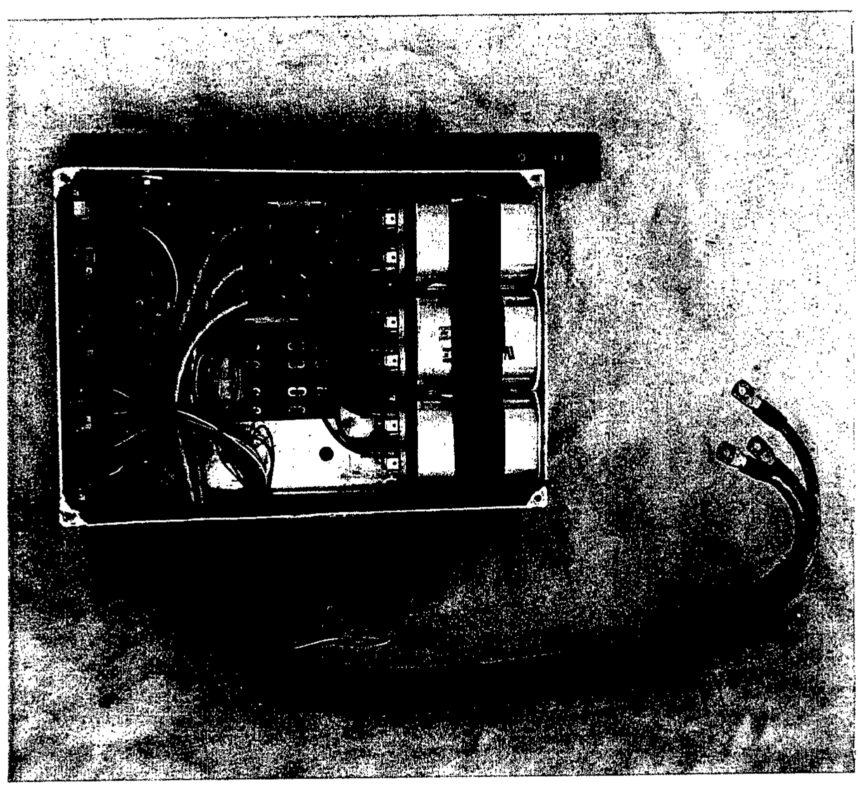


Photo 3 – The Moller rotary engine is an air-cooled single rotor Wankel type. For this application it was fitted with timed electronic fuel injection and a 12 V electric starter motor. An automotive style exhaust system was used. Fuel was 50:1 gasoline/oil premix.

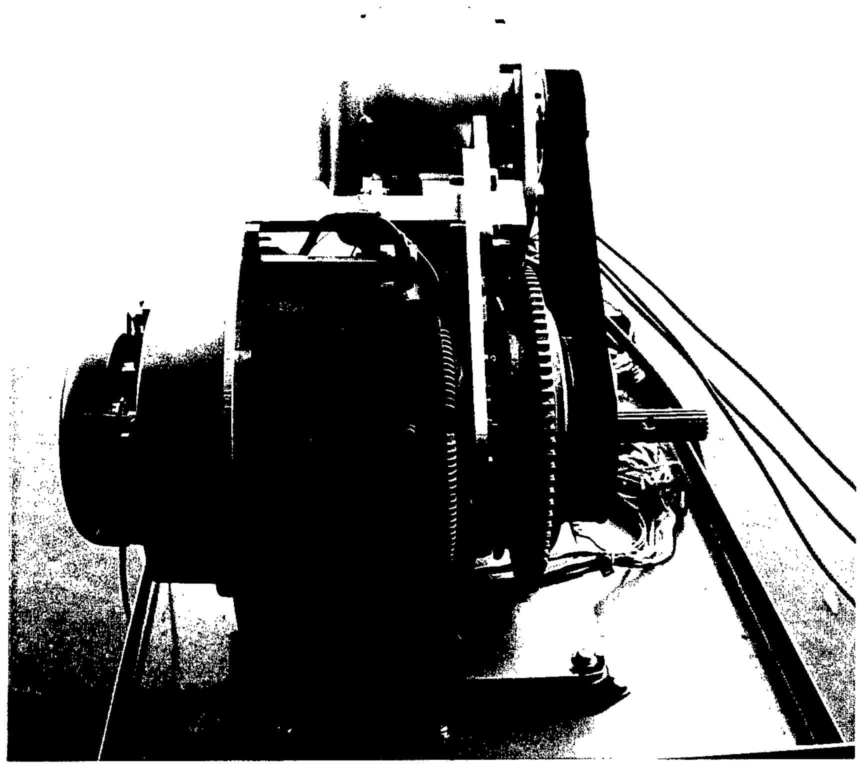


Photo 4 – The belt-drive uses a 30 mm x 8mm-pitch drive belt and operates at a 1.4:1 speed multiplication ratio. The alternator support structure mounts directly to the Moller engine. A revised shaft and drive-end bearing carrier were the only modifications required to convert the alternator from direct drive to belt-drive.

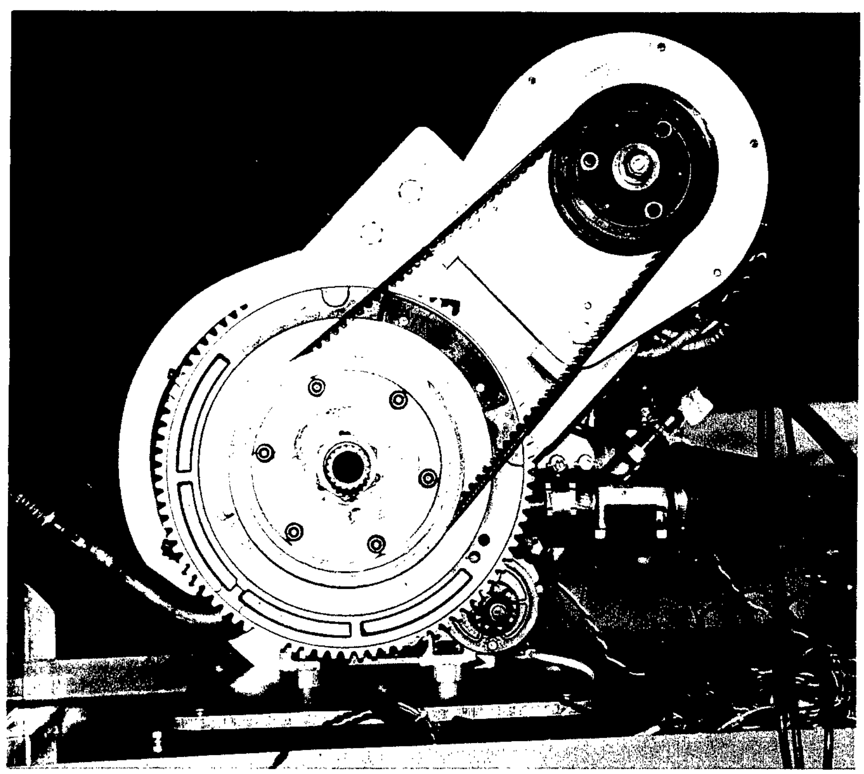


Photo 5 – Dynamometer testing was used to determine critical design features of the range extending alternator and control system. Eight different configurations were tested during the design and development phase. The final design, shown here, produces 20kW DC over a voltage range of 300 V to 390 V with efficiency of 90% to 91%.

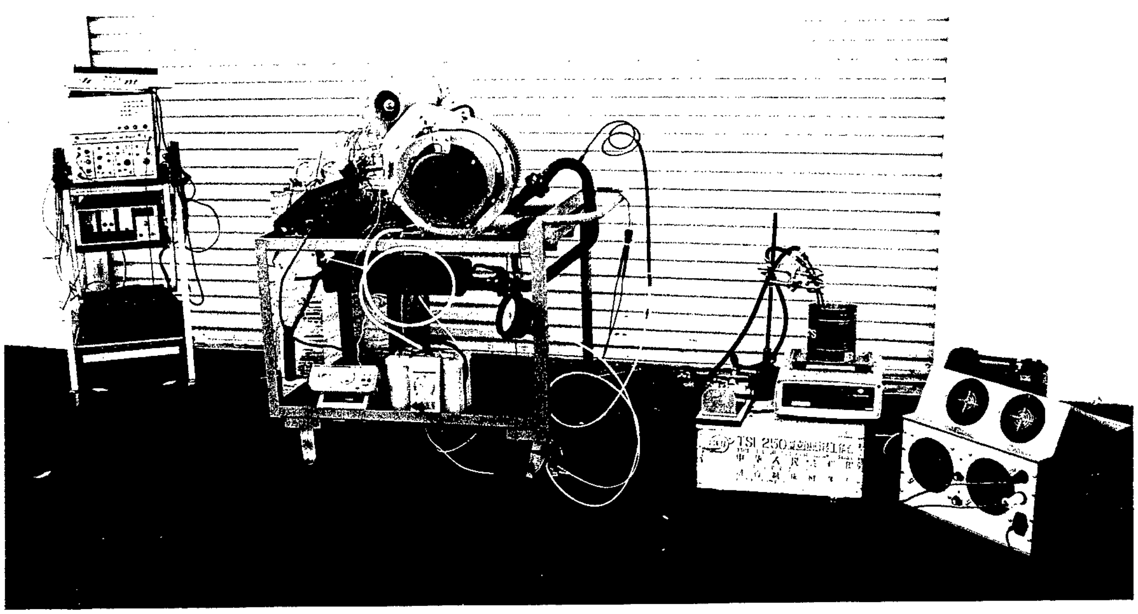


Photo 6 – Demonstration of the power system was fully instrumented to measure operating performance. From left to right: oscilloscope used to measure engine speed, fuel injection timing and pulse-width, and ignition timing; engine stand instrumented for output voltage and current, engine block temperature, exhaust oxygen sensor voltage, and exhaust backpressure; gravimetric fuel mass flow measurement apparatus; and air-cooled resistive load for dissipation of alternator output. In the demonstration, the maximum electrical output observed was 14.9 kW DC due to power limits of the engine. Fuel consumption was 0.72 kg/kWh.

Defense Advanced Research Projects Agency
Cooperative Agreement MDA972-95-2-0011
and modifications through P00012
Quarterly Report
January 1 to March 31, 1998

APPENDIX

AVCON
FINAL TEST REPORT

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Advanced Technology in Motion Control

AVCON

Final Test Report

for

CALSTART

AVCON, Inc.
21050 Erwin Street
Woodland Hills, CA 91367

1998

TABLE OF CONTENTS

1.0 PURPOSE and SCOPE:

The purpose of this test report is to present test set up, test data, and conclusions of the tests conducted on the Eddy Current Tester. This report constitutes Task 12 of the "Program to Minimize Losses in Mechanical Batteries for Electric Vehicles".

2.0 APPLICABLE DOCUMENTS:

Acceptance Test and Controller Optimization Procedure (ATP) for Avcon Magnetic Bearing Systems: AVCON DWG NO. 90-10308, Rev. Prel. B.

3.0 ATP TESTS:

This section defines the test setups & tests conducted on the Magnetic Bearing System that was used for the Eddy Current tests. These tests were conducted in accordance with Test Procedure referenced in section 2.1. Figure 1 presents a layout of the test rig.

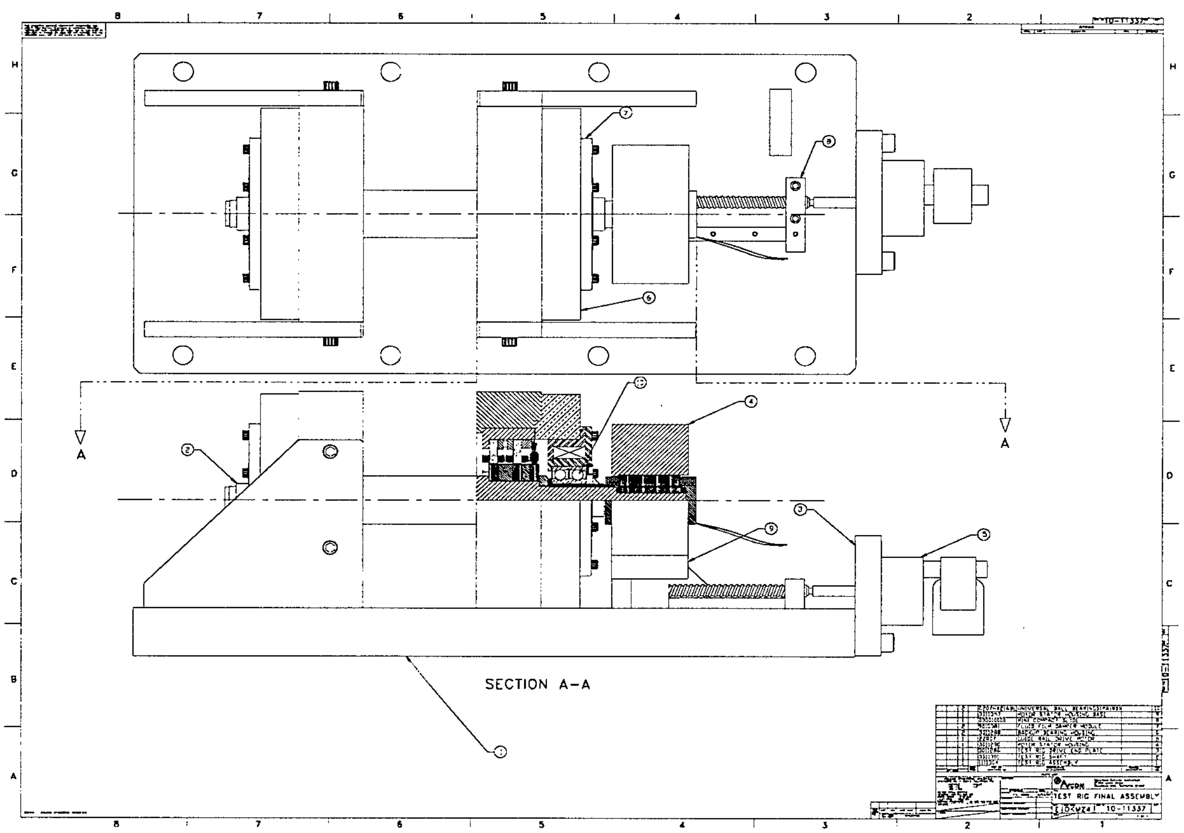


Figure 1. Test Rig System Assembly

3.1 PWM Power Amplifier Optimization (Sec. 6.2.4 Ref 2.1):

The PWM Power Amps (PA) were optimized for Band Width (BW) in accordance with Section 6.2.4 of the ATP (Ref 2.1). With R28 = 330 k OHM, on the PA maximum BW of the PA can be realized without gain peaking. Test data for this section is given in APPENDIX 1A. Test set up is given in Figure 2.

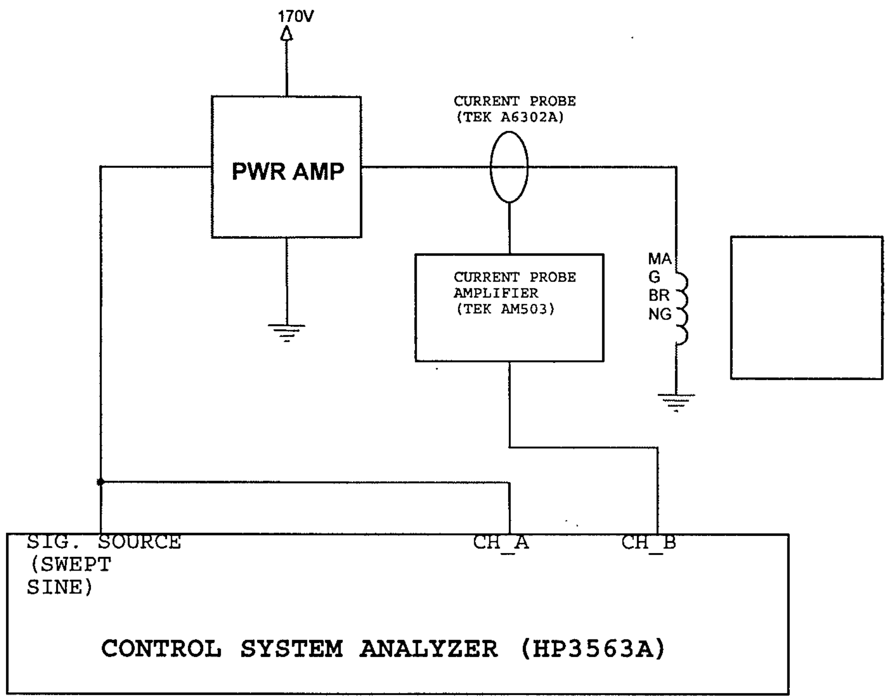


Figure 2. Power Amplifier Transfer Function

3.2 Flux Coil AC Calibration:

Test data is given in APPENDIX 1B.

3.3 Sensor Noise Measurement (Sec. 6.3.4 Ref 2.1)

The purpose of this test is to measure sensor signal to noise ratio in presence of PWM power amplifiers. The test is conducted in accordance with the ATP (Ref 2.1). Test data is given in APPENDIX 1C.

3.4 Transfer Function Measurements (Sec. 7.2 Ref 2.1)

The compensator (DSP Card), System Open Loop, Closed Loop, etc., transfer functions, identified in Section 7.2 (& its sub sections) of the ATP (Ref. 2.1) were measured. Test data is given in APPENDIX 1D.

4.0 EDDY CURRENT MEASUREMENTS:

4.1 Coast Down Testing

With the test rig assembled and installed in the spin pit, the system was spun up to a peak speed of 11,100 rpm and the motor disengaged. The coast down time to zero speed was then recorded. This data is presented in Appendix 2. Also recorded are the ac and dc currents in the system during testing. The ac currents would be due to unbalance response of the bearings. DC currents would be due to the static load of the shaft on the bearings and any catcher bearing-magnetic bearing misalignment in the system. The system for this testing was centered in the catcher bearings to minimize any contact during spin testing. Position power spectrums are also included to indicate that no instability is present in the system.

The final set of test data utilizes the optimized bearing configuration. Once this bearing was installed, the testing was conducted in the same manner as all previous testing.

4.2 Bearing Rotating Loss Calculation

Coast down testing includes the effects of bearing eddy current and hysteresis losses, as well as windage losses. In order to determine the net contribution of windage and electrical losses in the overall resistance of a shaft rotating while suspended by magnetic bearings, the windage loss must be subtracted from the test data

The test fixture was run in two separate configurations. The first configuration was with open slots in the magnetic bearing stator. In the second configuration, slot wedges were installed into the slot openings with the attempt to reduce eddy current losses. There was no appreciable difference between the performance of the two configurations.

The graph in Figure 3 shows the total power loss from the test data (data), the calculated windage loss from analysis (windage), and the resulting loss which is the difference of the two (e-power). What this shows is for this test rig windage is a small contributor to total rotating power loss. While the electrical losses are dominate, they are still very low for the magnetic bearings, on the order of 10.25 watts at 10,000 rpm for both bearings, or 5.125 watts per radial bearing. Table 1 presents the windage loss calculation. Table 2 presents this calculation for the bearing losses.

CALSTART: Power Loss vs. Rotor Speed

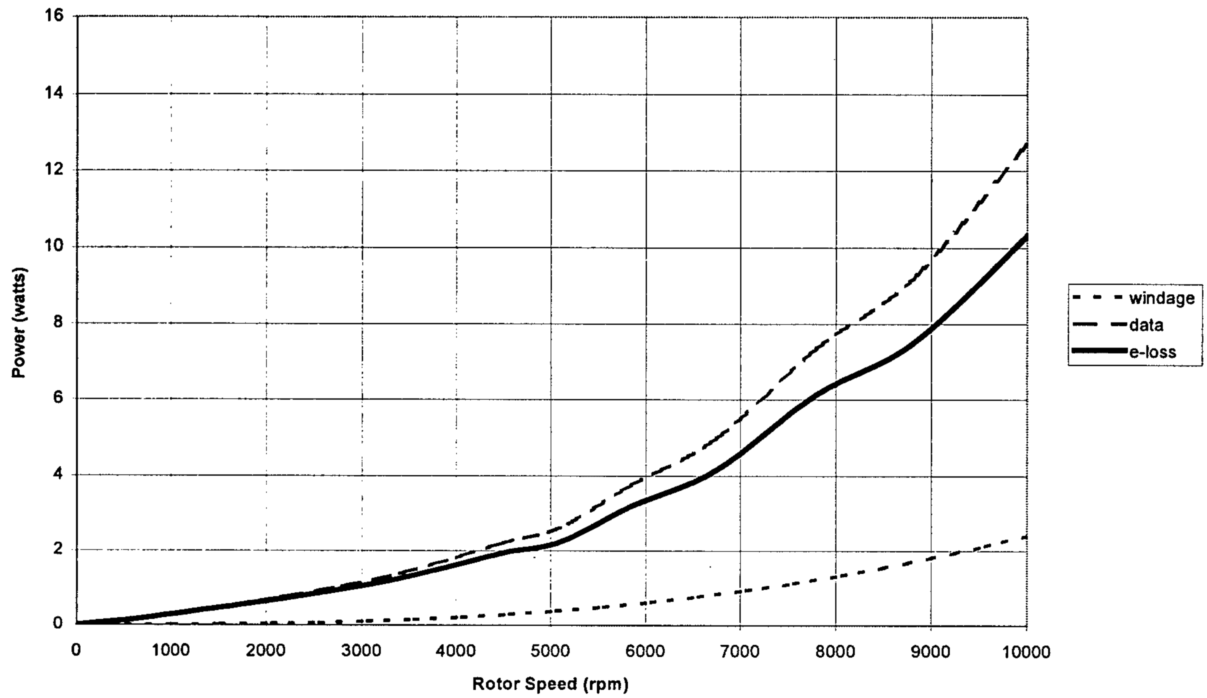


Figure 3. Bearing Rotating Power Loss

Table 1. Windage Power Calculation Data

PREDICTED RESULTS - WINDAGE								
n(rpm)	Cd1	Cd2	Cd3	Cd4	Cd5	wdot	dt	power
10000	0.00885	0.01396	0.00444	0.00531	0.00703	0.654	0	2.405
9500	0.00898	0.01421	0.00450	0.00537	0.00713	0.618	82	2.090
9000	0.00912	0.01449	0.00454	0.00544	0.00723	0.563	89	1.802
8500	0.00927	0.01478	0.00460	0.00551	0.00734	0.509	98	1.541
8000	0.00943	0.01512	0.00466	0.00559	0.00745	0.459	108	1.306
7500	0.00962	0.01546	0.00472	0.00567	0.00758	0.410	121	1.094
7000	0.00982	0.01585	0.00480	0.00577	0.00772	0.364	135	0.907
6500	0.01004	0.01628	0.00487	0.00587	0.00788	0.320	153	0.741
6000	0.01029	0.01677	0.00496	0.00598	0.00805	0.279	175	0.595
5500	0.01056	0.01733	0.00506	0.00611	0.00825	0.240	202	0.470
5000	0.01088	0.01797	0.00517	0.00625	0.00847	0.204	236	0.362
4500	0.01124	0.01872	0.00529	0.00642	0.00873	0.170	280	0.272
4000	0.01167	0.01961	0.00544	0.00661	0.00903	0.139	339	0.198
3500	0.01219	0.02068	0.00561	0.00684	0.00938	0.111	419	0.138
3000	0.01283	0.02203	0.00582	0.00711	0.00982	0.085	535	0.091
2500	0.01364	0.02379	0.00608	0.00746	0.01037	0.063	709	0.056
2000	0.01474	0.02623	0.00642	0.00792	0.01112	0.043	992	0.031
1500	0.01636	0.02991	0.00690	0.00858	0.01219	0.027	1504	0.014
1000	0.01908	0.03643	0.00767	0.00964	0.01397	0.014	2602	0.005
500	0.02545	0.05297	0.00931	0.01195	0.01797	0.004	5789	0.001

The fact that the slot wedges for the improved design made no difference in performance points to one of three possible reasons; (1) The wedges are not effective, though the analysis shows they significantly reduce the changes in field at the air gap; (2) The losses in the conventional bearing are low enough that the improvement made by the wedges is so minimal that it is not apparent in the test data; (3) the control coil offsets to maintain the shaft position and the ac unbalance control fields in this system generate the dominate eddy currents. The most probable is item 3. This can only be verified by running additional testing at various offset positions to quantify the effect of control coil currents on system performance.

Table 2. Bearing Power Calculation Data

time	rpm	w	t-ave	alpha	w-ave	power-watts	rpm-ave	windage-watts	e-power
0	11100	1162.4	26.5	3.557	1068.1	13.334	10200	2.531	10.803
53	9300	973.9	69.5	2.856	926.8	9.290	8850	1.724	7.566
86	8400	879.6	110.5	2.565	816.8	7.353	7800	1.221	6.132
135	7200	754.0	158.5	2.005	706.9	4.975	6750	0.824	4.151
182	6300	659.7	209	1.745	612.6	3.753	5850	0.558	3.195
236	5400	565.5	258.5	1.396	534.1	2.617	5100	0.384	2.233
281	4800	502.7	304.5	1.337	471.2	2.211	4500	0.272	1.939
328	4200	439.8	354	1.208	408.4	1.732	3900	0.186	1.546
380	3600	377.0	409	1.083	345.6	1.314	3300	0.119	1.195
438	3000	314.2	469.5	0.997	282.7	0.990	2700	0.07	0.920
501	2400	251.3	535	0.924	219.9	0.713	2100	0.036	0.677
569	1800	188.5	606	0.849	157.1	0.468	1500	0.014	0.454
643	1200	125.7	734	0.690	62.8	0.152	600	0.002	0.150
825	0	0.0	412.5	0	0	0	0	0	0.000

4.3 Windage Loss Calculation

Windage Power loss = P =(1.356 watt-sec/ft-lb)$\pi C_d \rho r^4 \omega^3 / g$ (in watts)

Ref. "Prediction of Windage Power Loss in Alternators" by James E. Vrancik; NASA TN D-4849

Modified for Calstart:

$$P = (1.356 \text{ watt-sec/ft-lb})\pi\rho\omega^3/g\,(r_1^4 l_1 C_{d1} + r_2^4 l_2 C_{d2} + r_3^4 l_3 C_{d3} + r_4^4 l_4 C_{d4} + r_5^4 l_5 C_{d5})\ \text{(watts)}$$

Where C_d, r and l are for the following locations:

1. Magnetic bearing rotor/stator gaps
2. Back-up bearing gaps
3. Large rotor dia not in gap
4. Center section dia
5. Motor rotor

ρ = air density ($lb/ft^{3)}$

r = radius of shaft (ft)

ω = angular velocity (rad/sec)

l= length of air gap (ft)

g = gravitational acceleration (32.2 ft/sec^2)

C_{d1}, C_{d2} = Drag coefficient defined by equation A: $1 = \sqrt{C_d}\left[2.04 + 1.768\ln\left(N_R\sqrt{C_d}\right)\right]$

C_{d3}, C_{d4}, C_{d5} = Drag coefficient defined by equation B: $1 = \sqrt{C_d}\left[-0.6 + 4.07\log_{10}\left(N_R\sqrt{C_d}\right)\right]$

Hint: use excel and range C_d from .0001 to .0600 incrementally.

N_R = Reynolds Number = VDρ/μ

V = velocity of air ≈ (ωr/2)(ft/hr)

D = hydraulic diameter = 2 X gap in (ft)

μ = air viscocity (lb/ft-hr)

ρ = air density (lb/ft^3)

n = rotor speed in rpm

Reynolds number calculation: (assume ambient air is at 1atm and 70°F)

ω = n(rpm)(2π rad/rot)(60 min/hr) = 2.977 E6 rad/hr

V = ωr/2 (ft/hr)

D = 2δ (ft)

ρ = .075 lb/ft^3 at 70°F and 1 atm

μ = .043 lb/ft-hr at 70°F and 1 atm

N_R (for gaps) = $VD\rho/\mu$ (dimensionless)

N_R (for open dia's) = $\omega r^2\rho/\mu$ (dimensionless)

Energy = $\frac{1}{2} J\omega^2$

Power = $\frac{dE}{dt} = J\omega\dot{\omega}$; for a shaft spinning down due to resistance.

Equating the two equations for power we obtain a relationship for $\dot{\omega}$:

$$\dot{\omega} = \frac{\pi\rho\omega^2}{Jg}(r_1^4 l_1 C_{d1} + r_2^4 l_2 C_{d2} + r_3^4 l_3 C_{d3} + r_4^4 l_4 C_{d4} + r_5^4 l_5 C_{d5})$$

$\dot{\omega}$ was calculated from the test data by using the following relationship for small increments:

$\dot{\omega} = \frac{\omega_i - \omega_{i+1}}{t_{i+1} - t_i}$; The numerator operators were reversed to result in a positive deceleration.

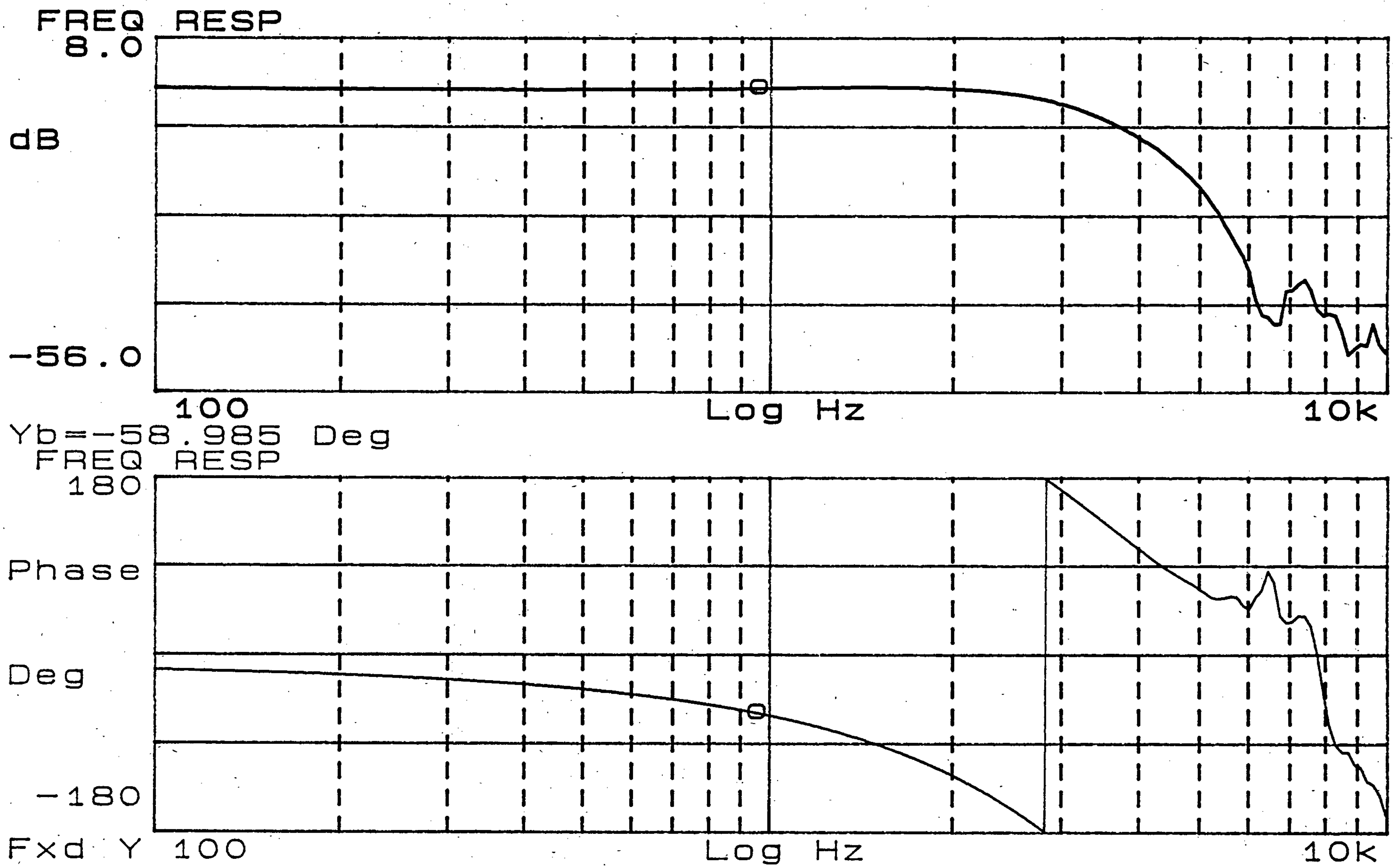
APPENDIX 1A

PA XFR FN

3/11/19

R28 = 330K

X=960.51 Hz
Ya=-910.23mdB

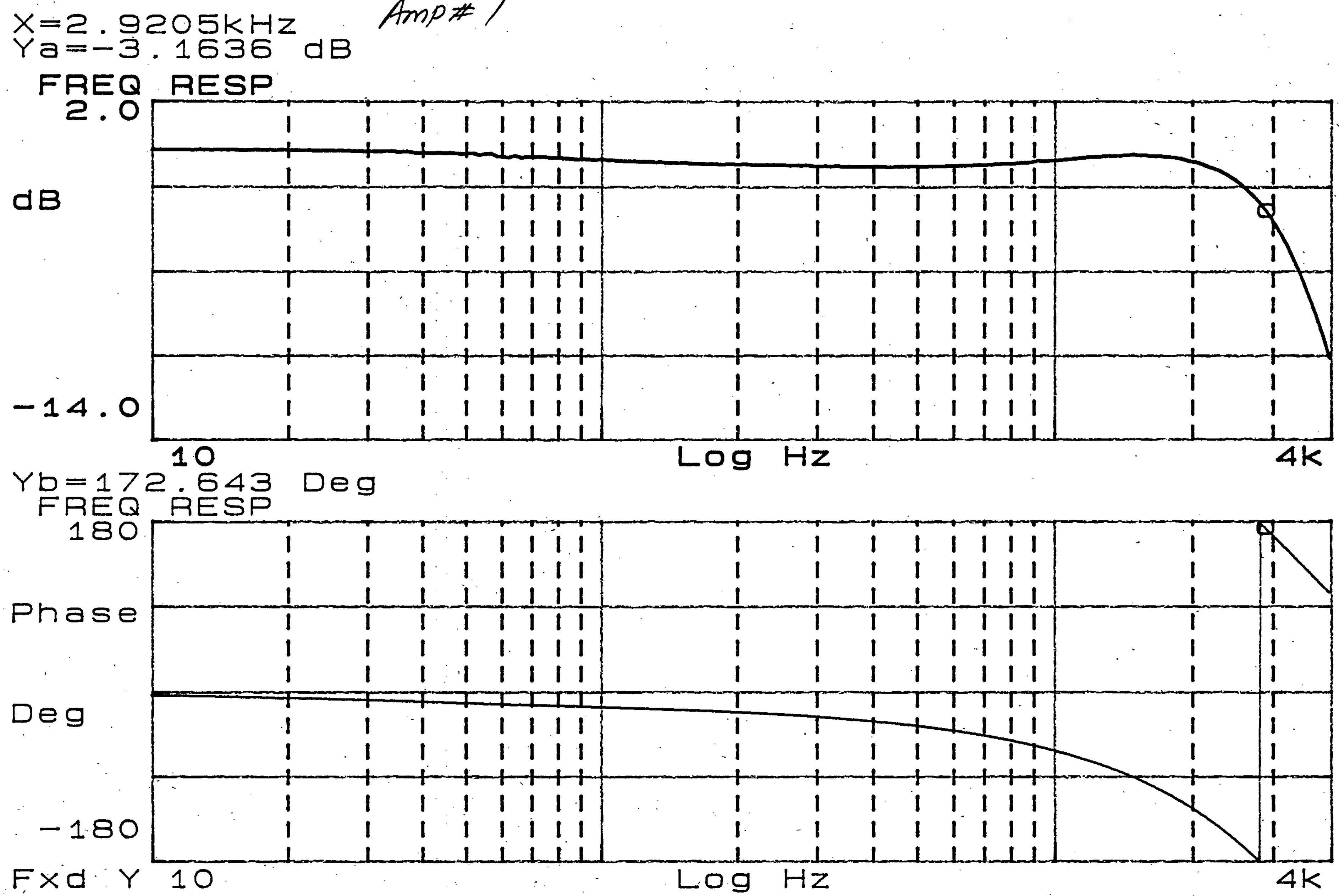


Calstart

1A-1

PA XFR FN (Curr. +/ command)
100 mV Swept Sine
Amp# 1

3/11/98



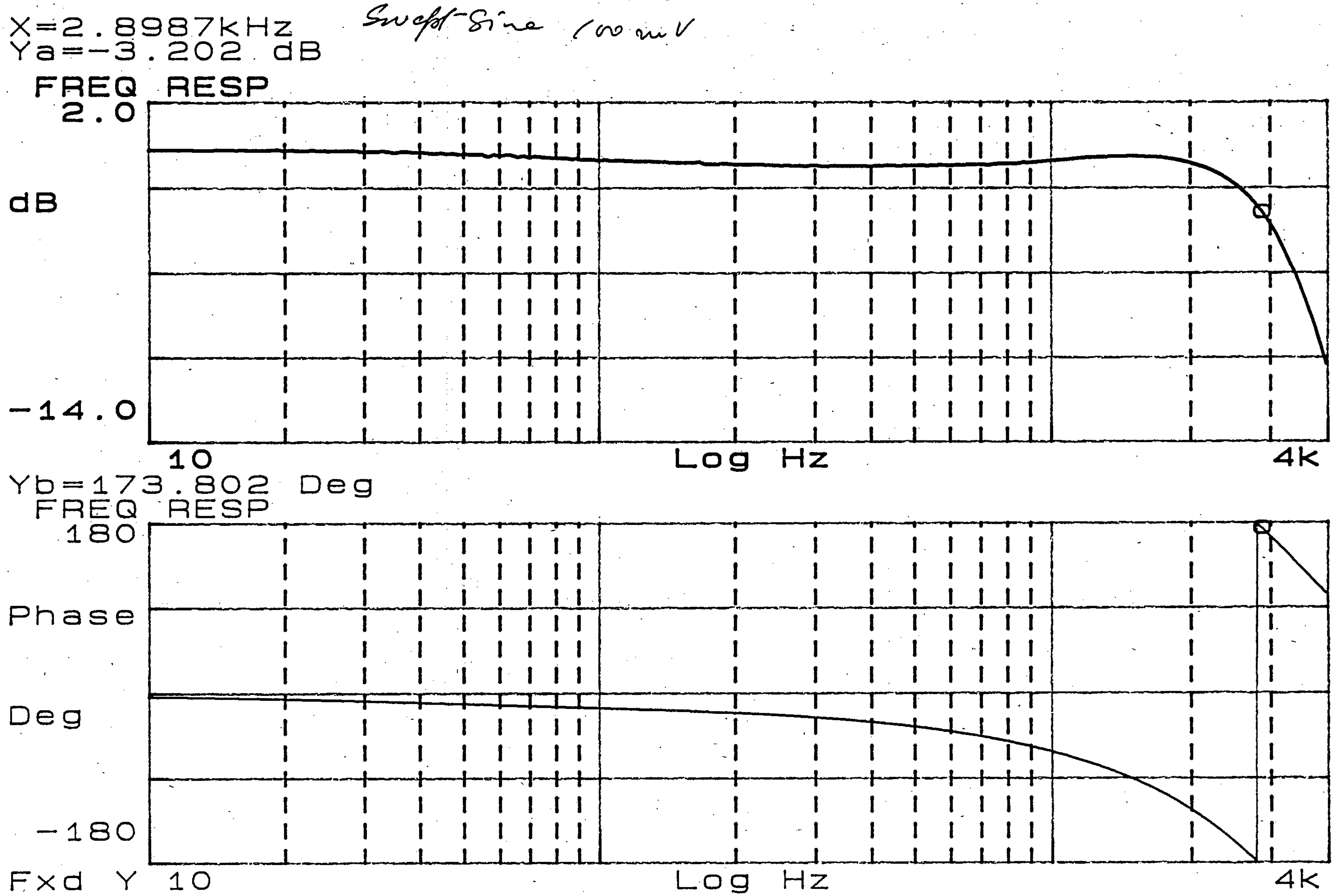
calsloor

1A-2

PA #2

PA XFR FXN
current/command
Swept-Sine 100 mV

2/11/11 3



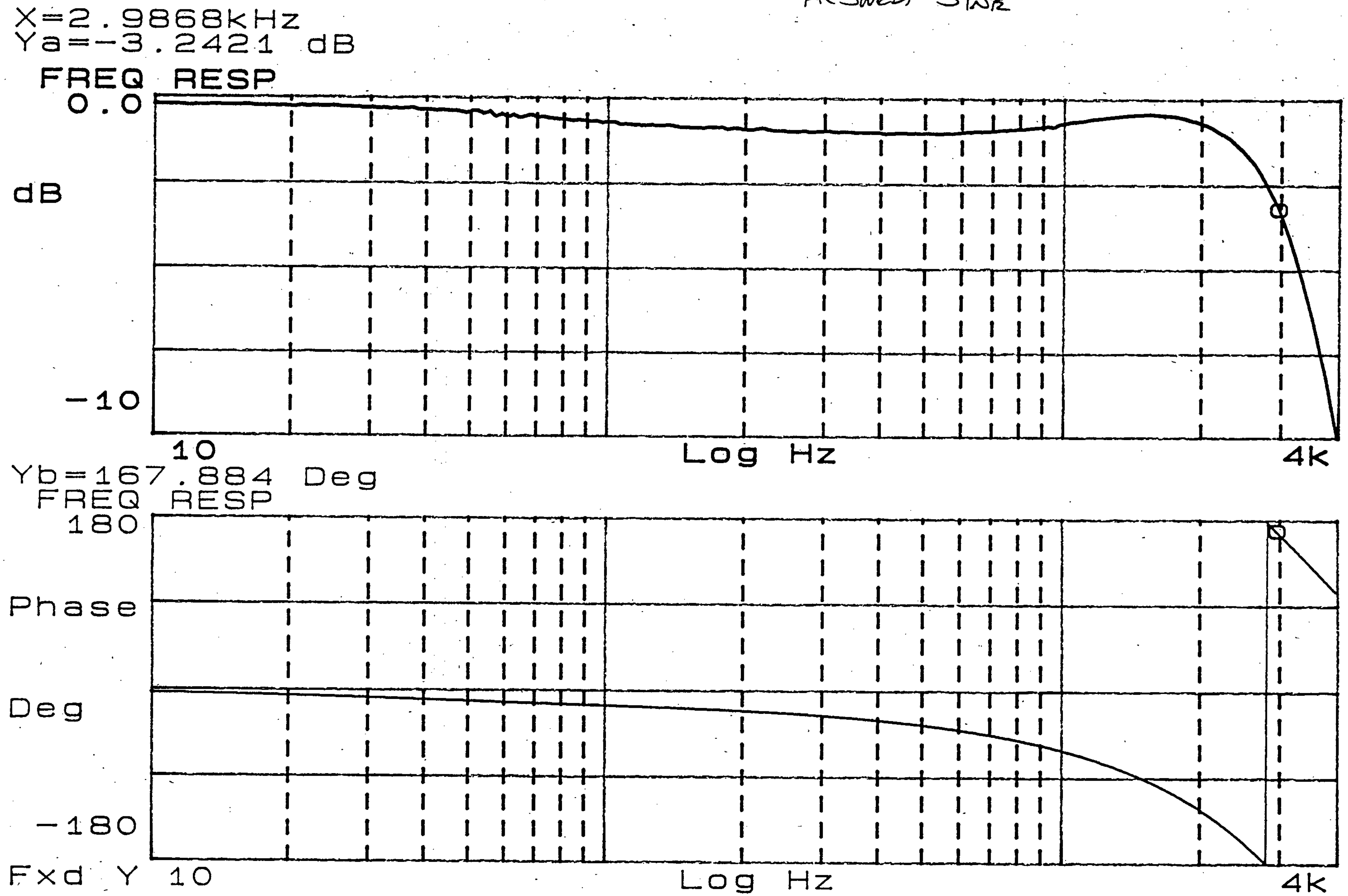
calstart

CALSTAR?

AMPLIFIER #3 TRANSFER FUNCTION (CURRENT/COMMAND) 100mVpk SWEPT SINE

3/?/98

9:30am



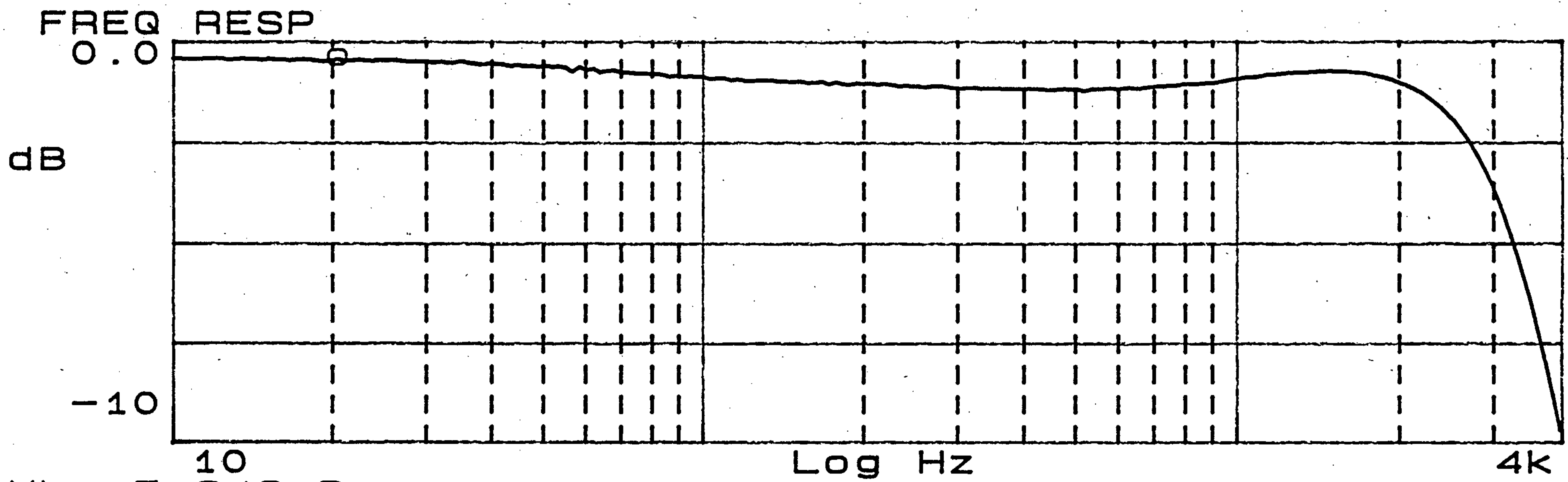
CALSTART

AMPLIFIER #4 TRANSFER FUNCTION (CURRENT/COMMAND)

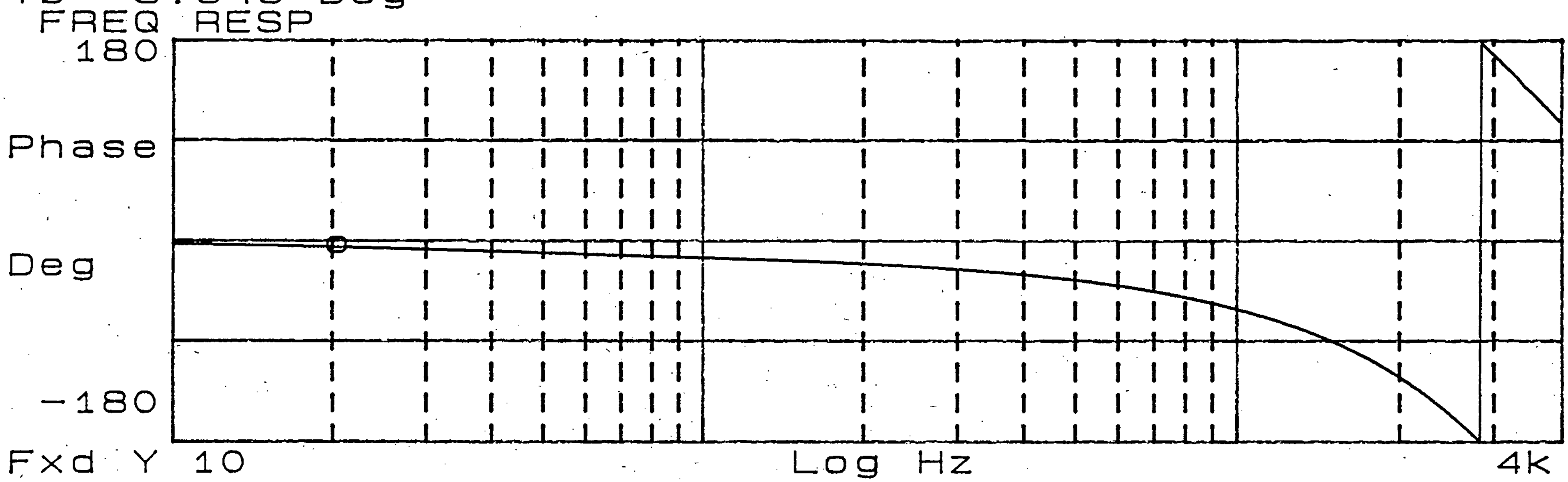
3/11/-
9:10 am

100mVp SWEPT SINE

X=20.523 Hz
Ya=-398.94mdB

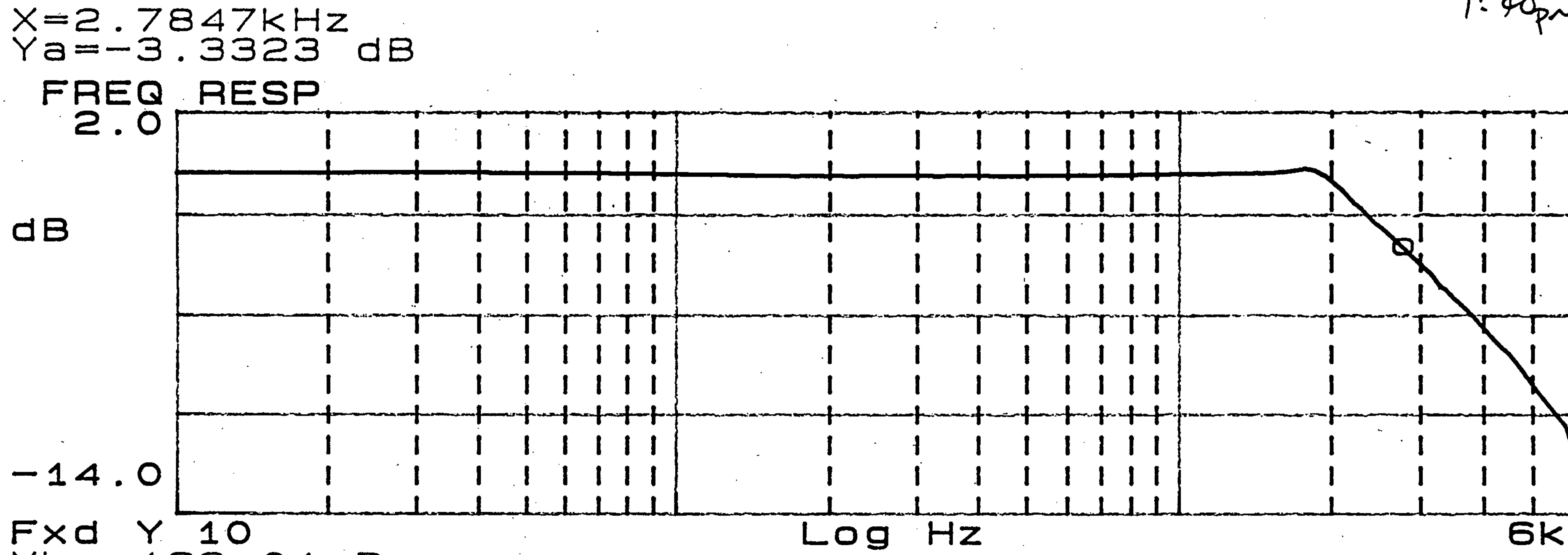


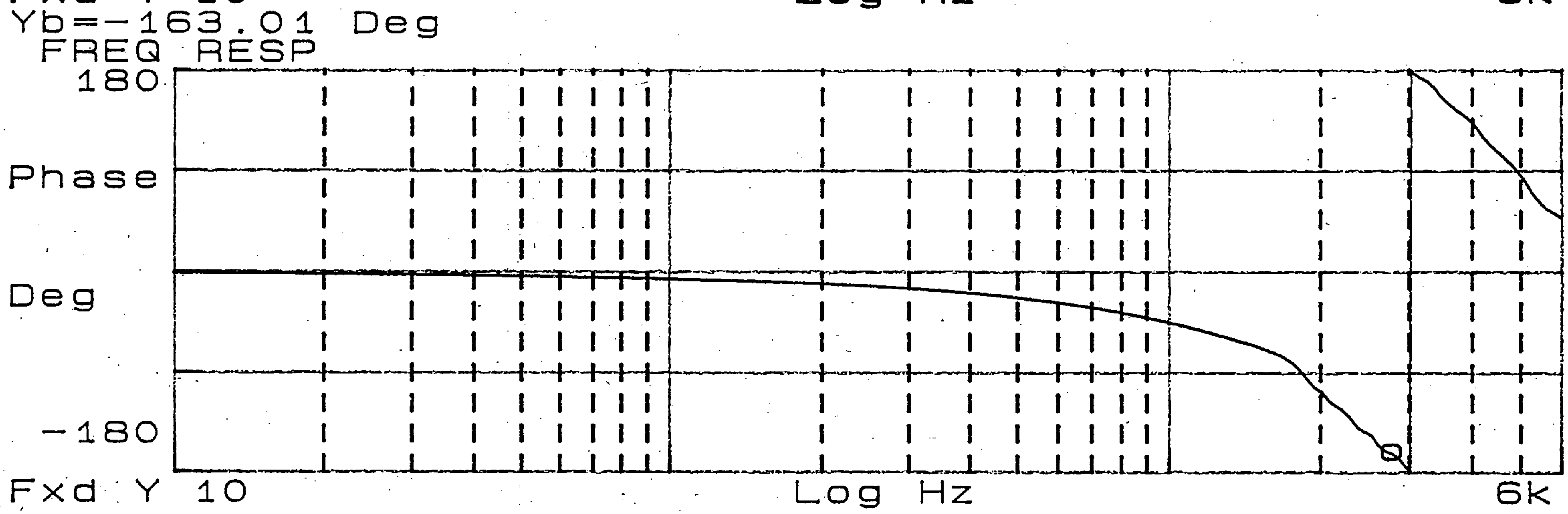
Yb=-5.646 Deg



CALSTAT

DA#4   500mVpk Swept Sine   Y1 (Series Parallel)   Current/Command   1/11/98 1:40pm





1A-6

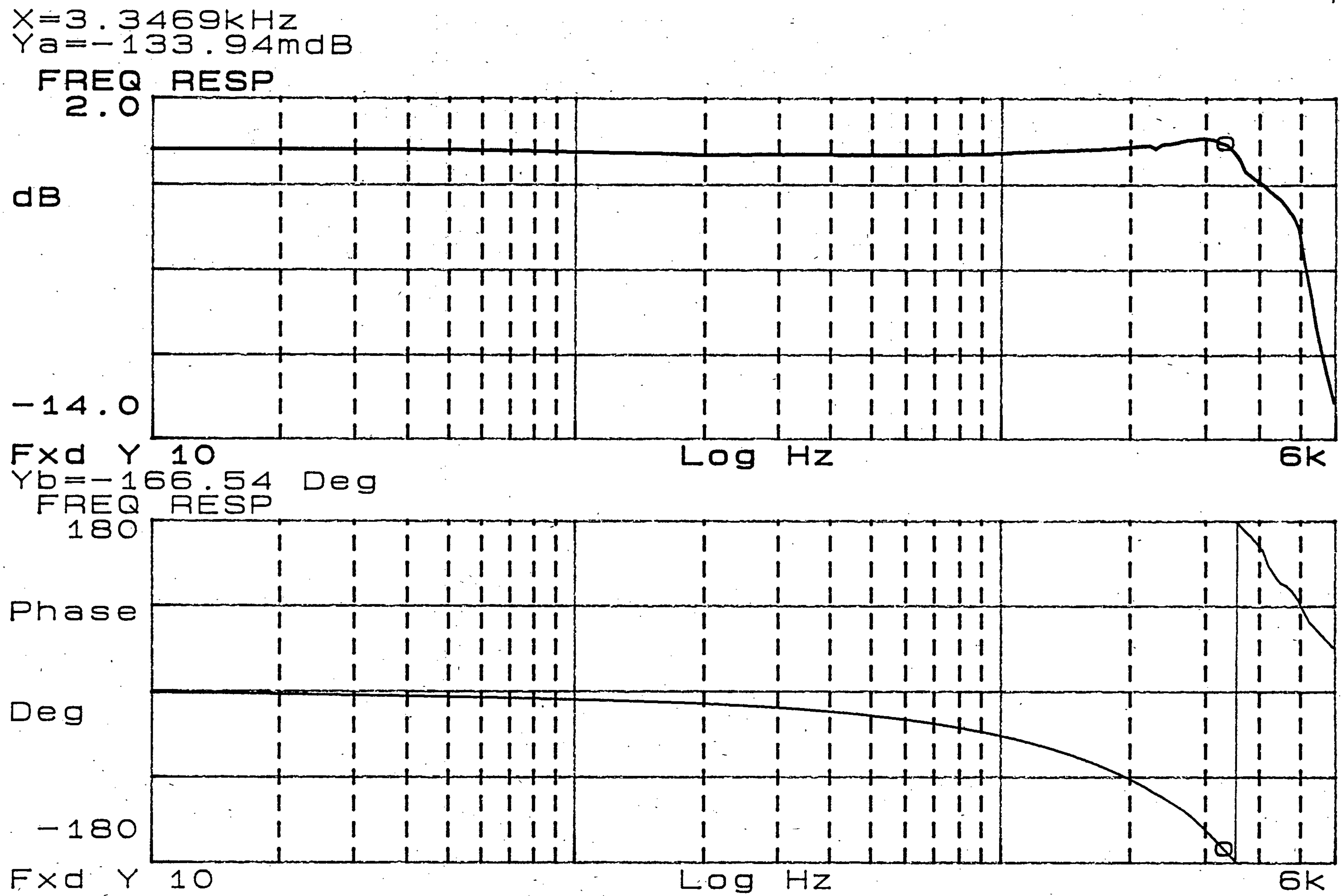
UNISTAR
PA#4

250 mVpk Swept Sine

Y1 (Series Parallel)

Current/Command

3/11/98
1:38pm



PA#4

Source Swept Sine 100 mV

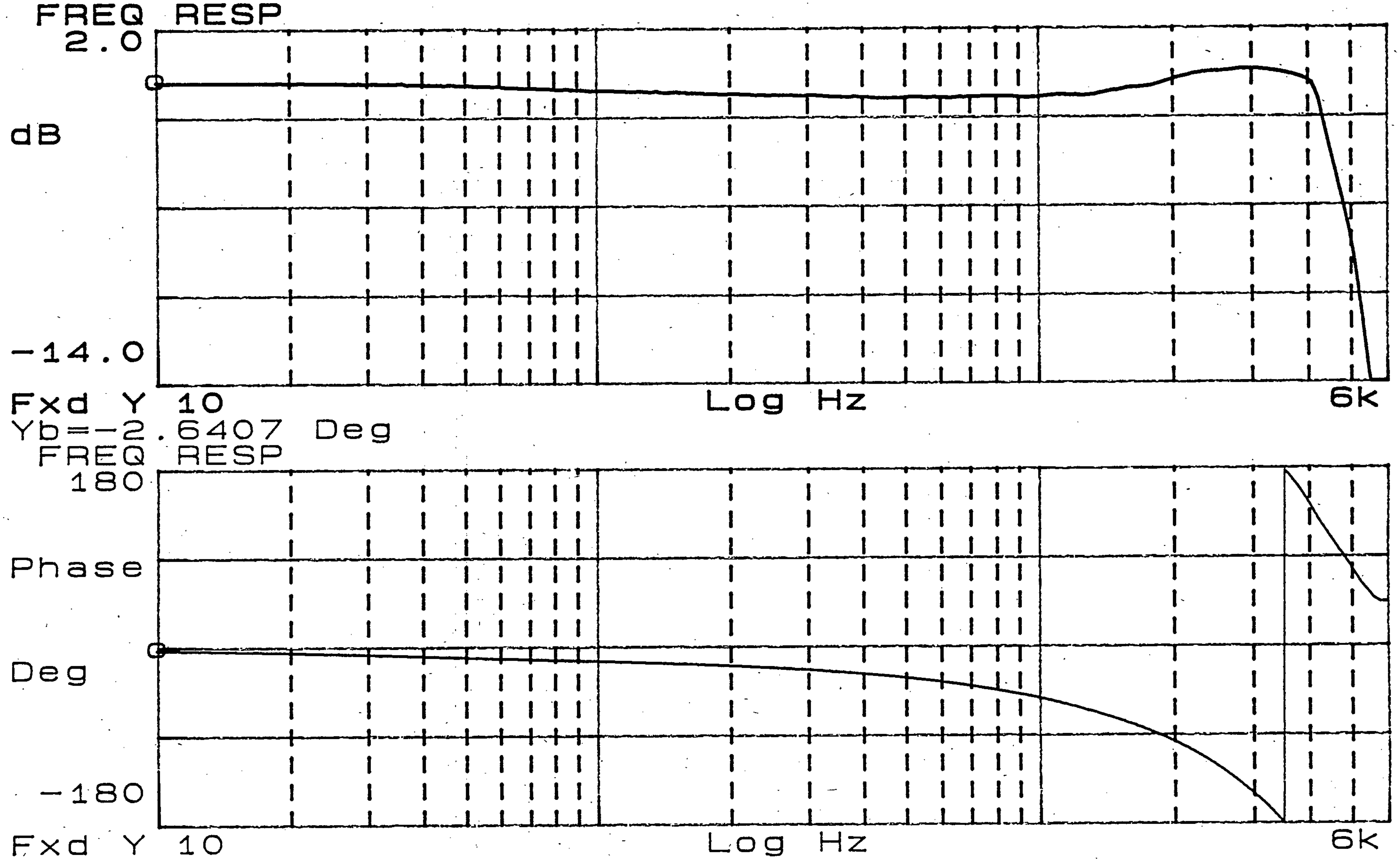
Load: Y1 ~~(series)~~ (Parallel)

Current/command

3/11/98

X=10 Hz

Ya=-374.52mdB



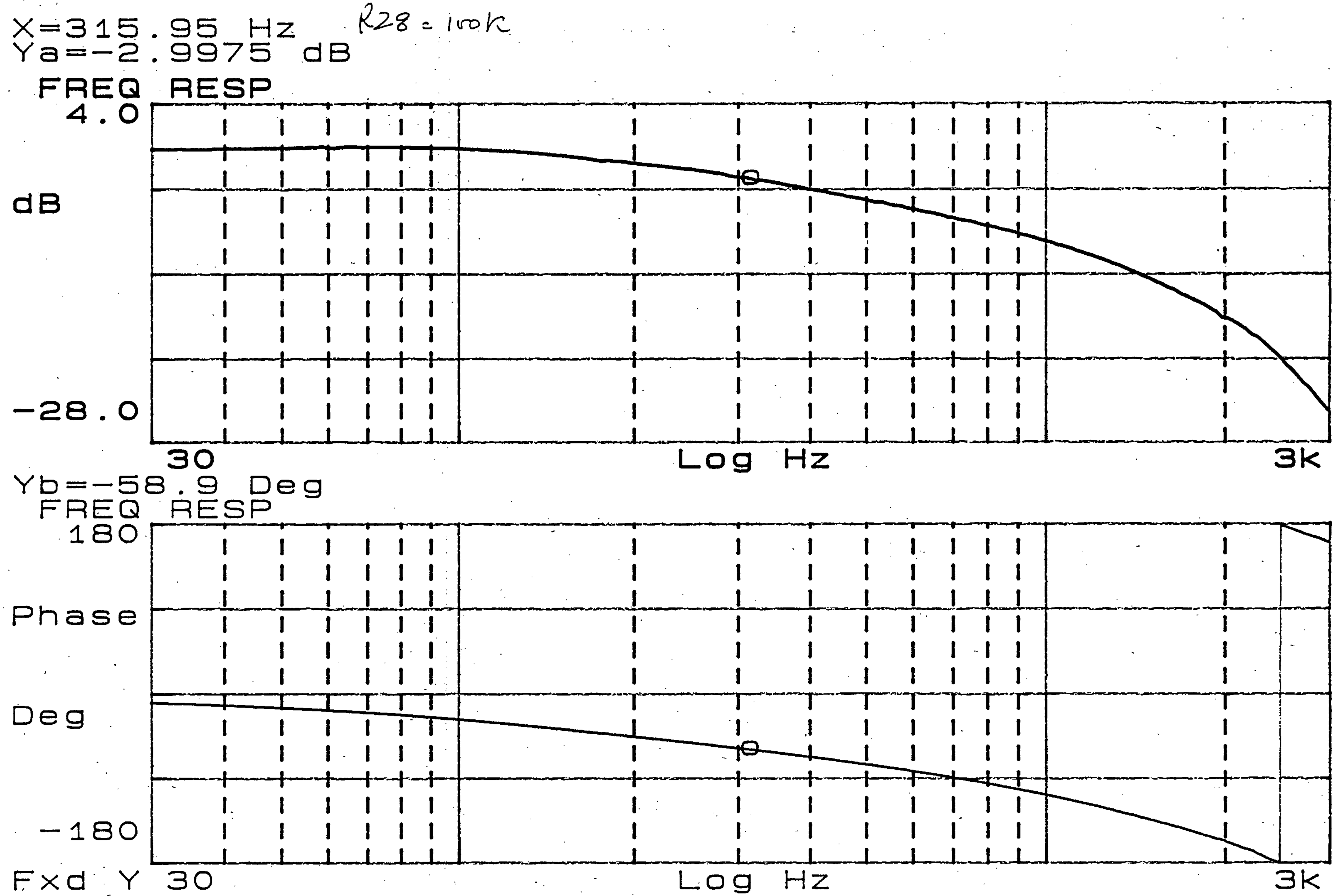
calstart

1A-9

μA XI-K I-N 3 /1/1998

Swept Sine 100 mVpk

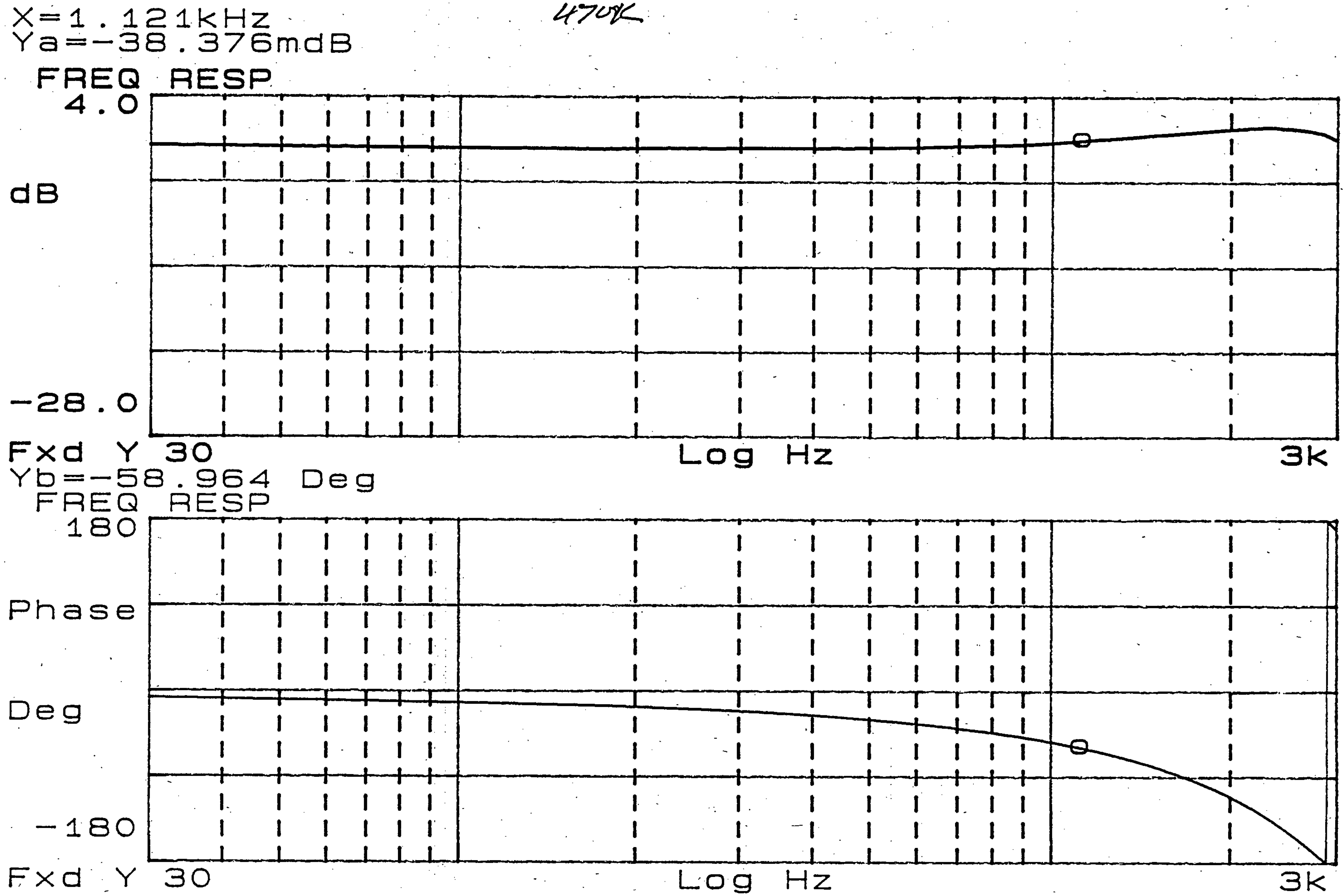
R28 = 100K



CalcTart

PA XFR FN 3/11/98

R28 = ~~500K~~ 470K



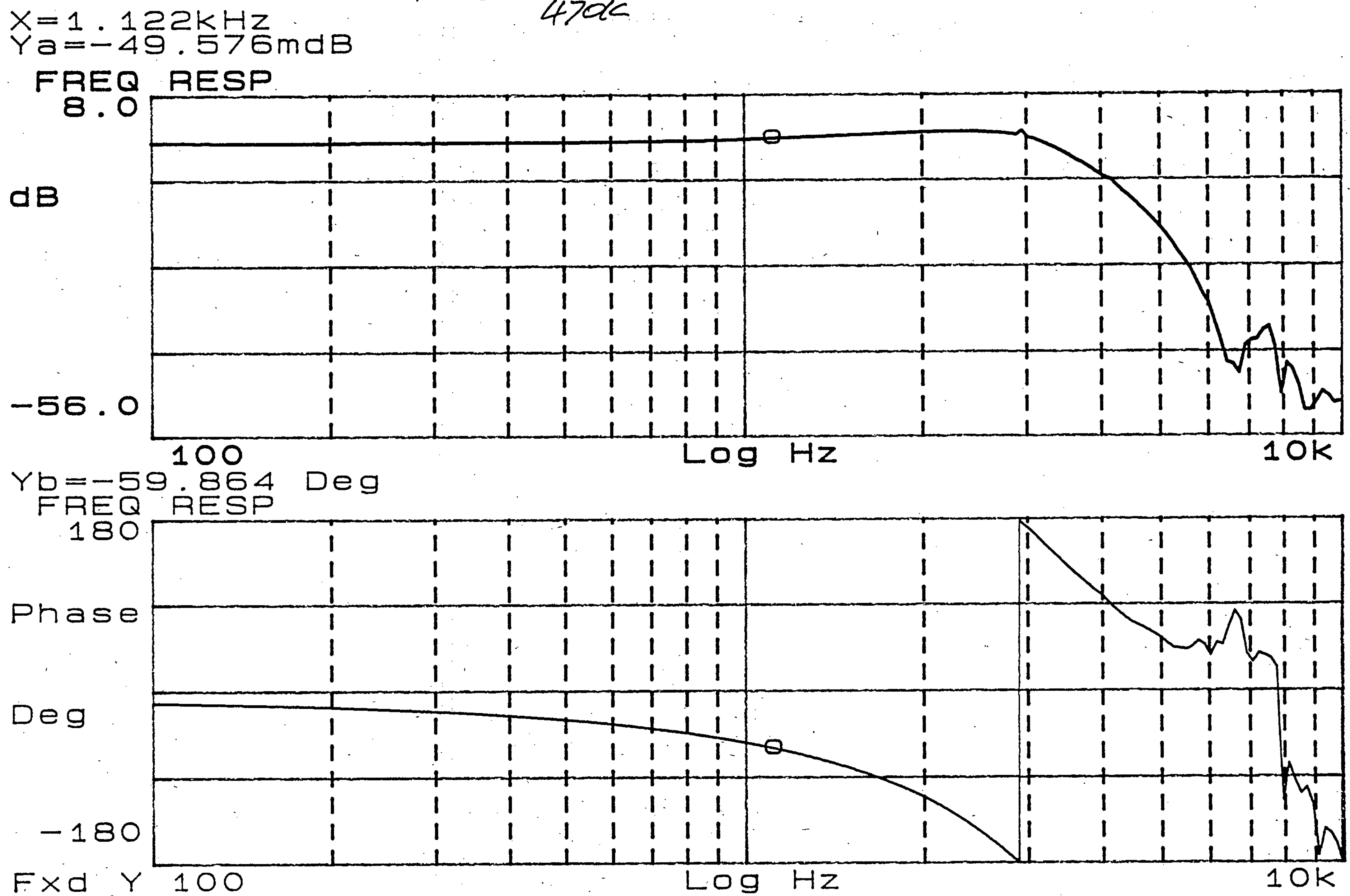
calstart

1A-10

PA XFR FN

R28 = ~~500k~~ 470k

3/11/9



Calstar

1A-11

APPENDIX 1B

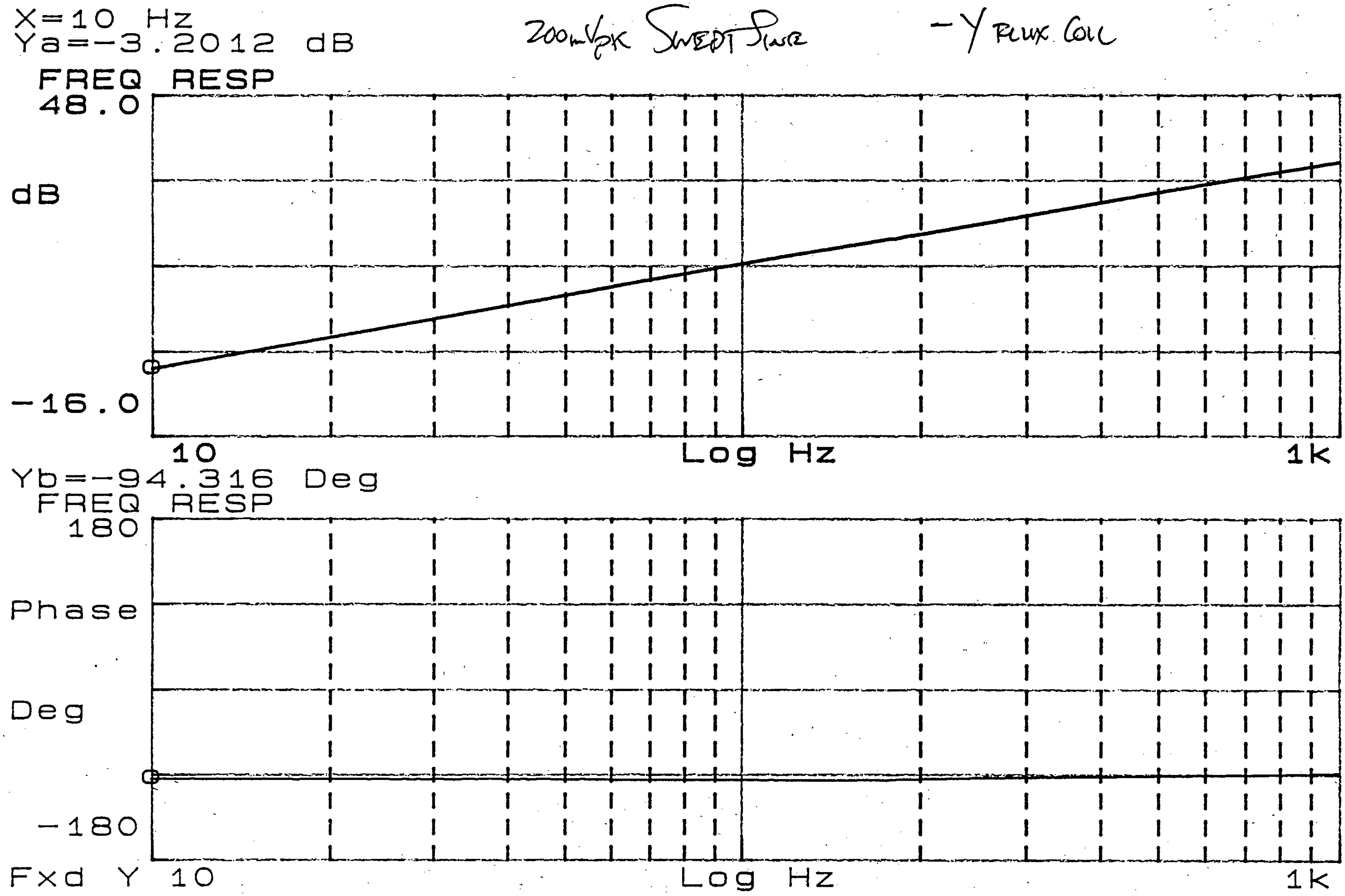
CATSTART 3/8

FLUX/CURRENT

OUTBOARD Y COIL

200mVpk SWEPT SINE

-Y FLUX COIL



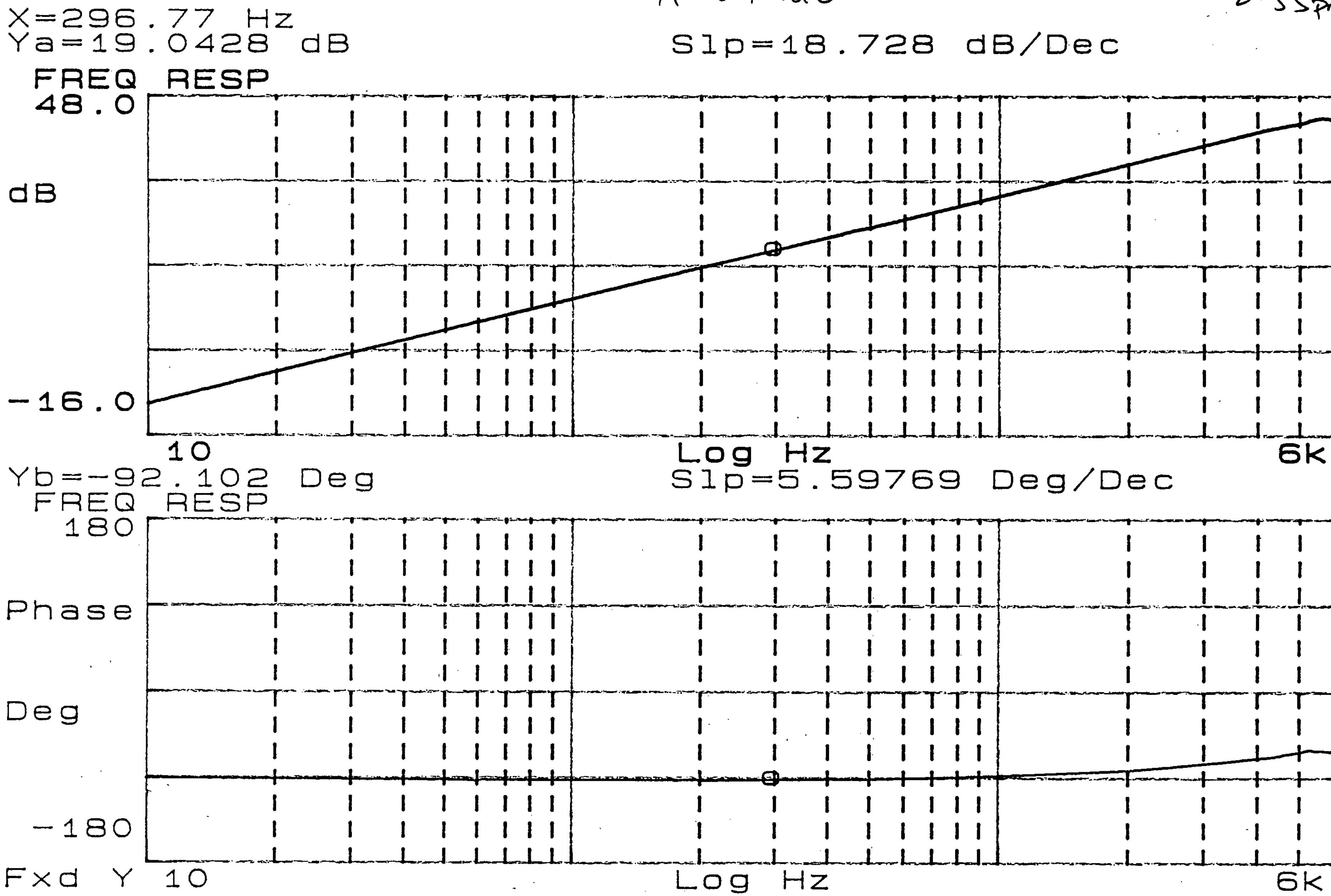
18-1

LACS in...
FLUX/CURRENT

100 mVpk
SWEPT SINE

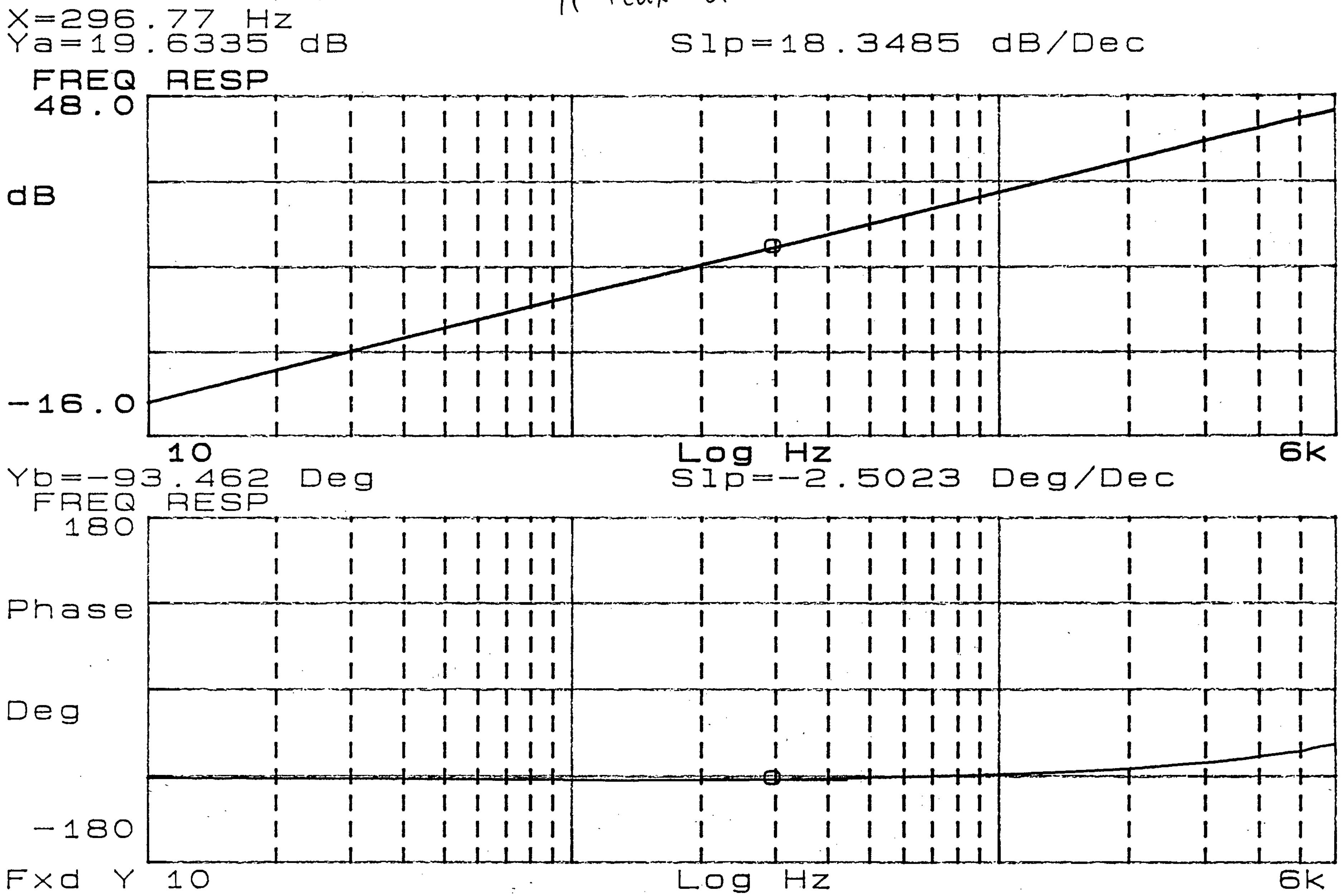
Y1 (SERIES PARALLEL)
-Y1 FLUX COIL

..'/98
2:55pm



1B-2

CALSTAR1 FLUX/CURRENT 250mVpk SWEPT SINE Y1 (SERIE, PARALLEL) -Y1 FLUX COIL 3/1 2:50pm

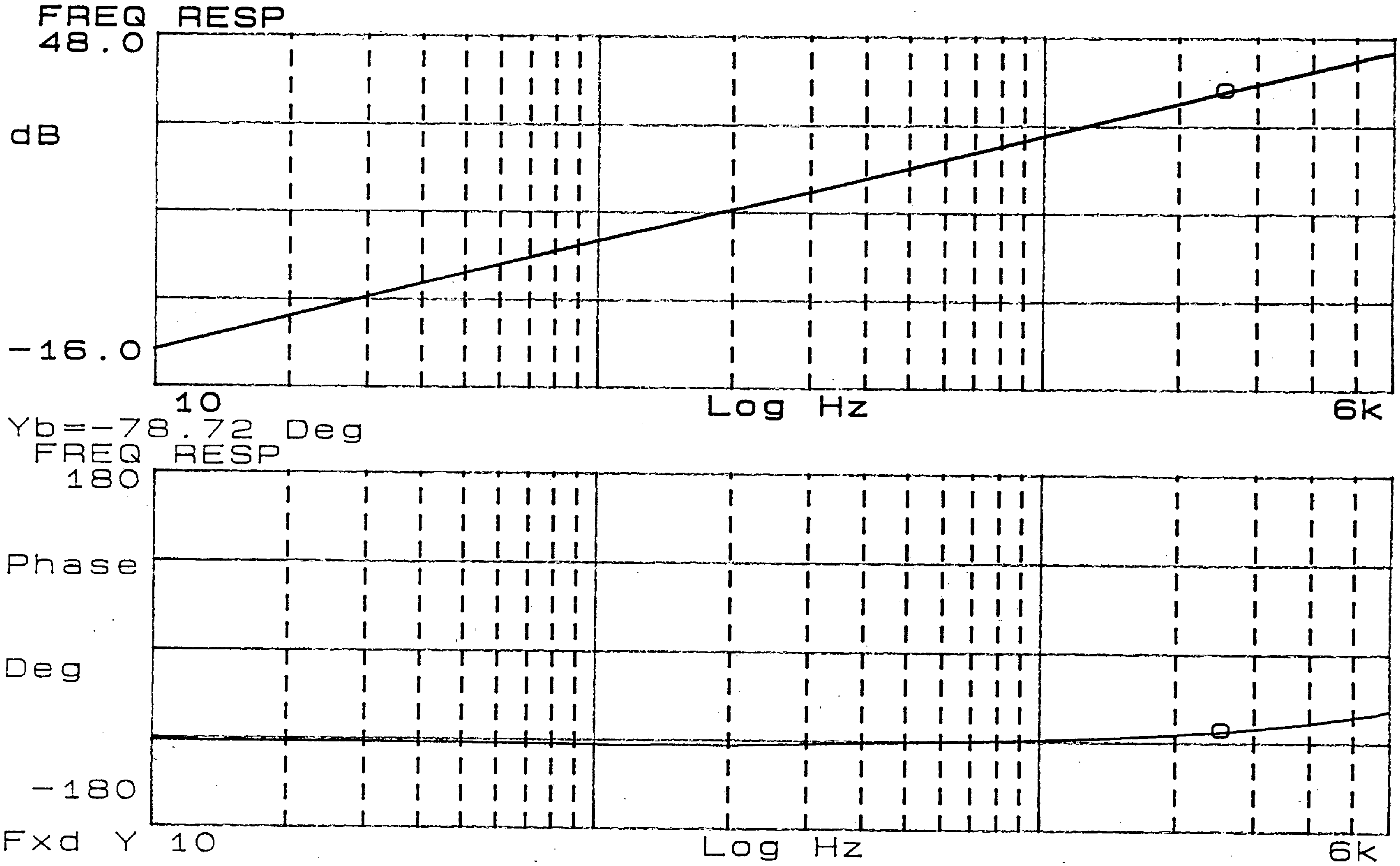


1BA3

FLUX/CURRENT 350mVpk SWEPT SINE Y1 (SERIES ... RALLEL) 3/11/90

-Y1 FLUX COIL 2:30pm

X=2.5502kHz
Ya=38.4188 dB



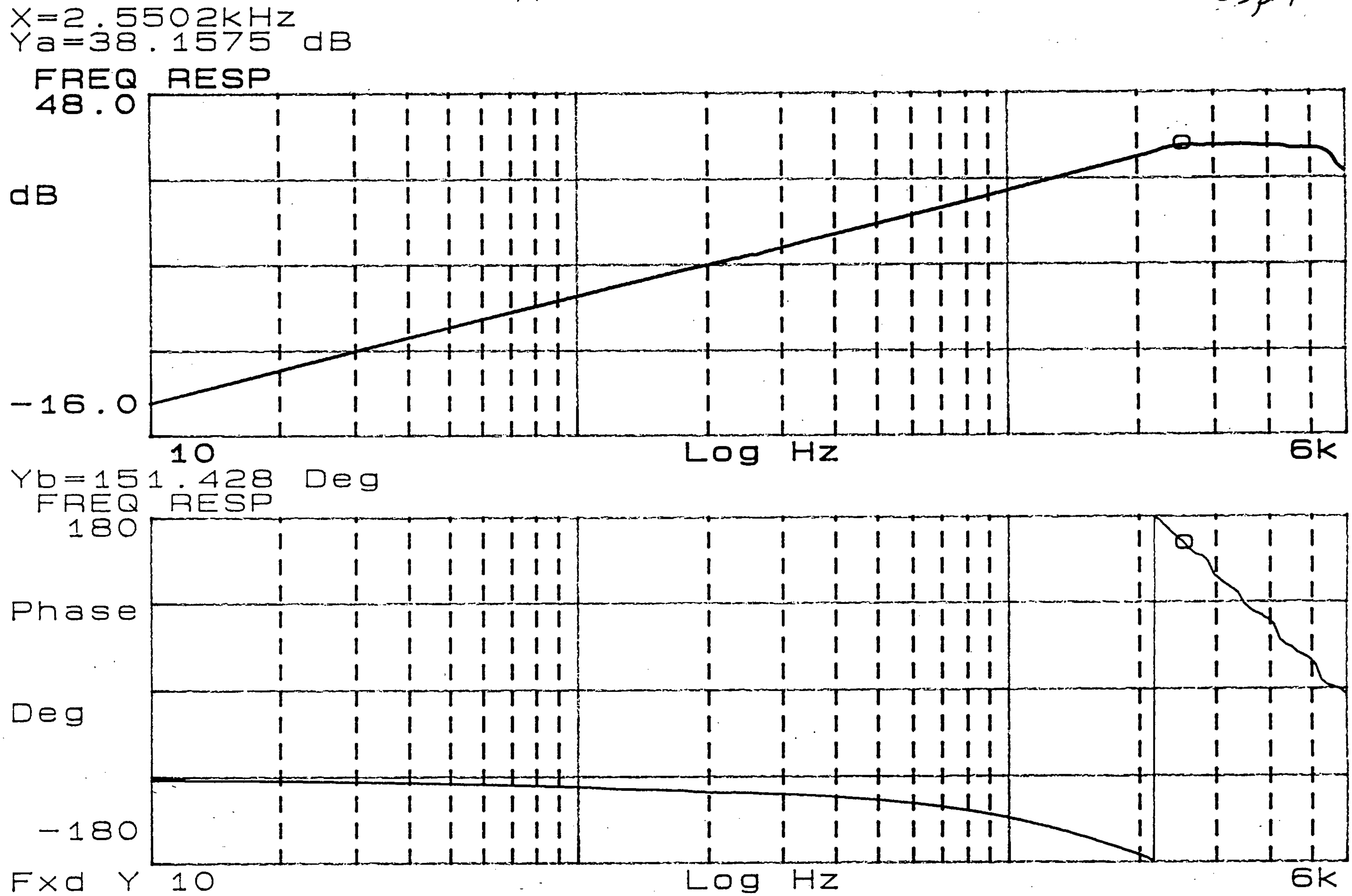
1B-4

CALSTART
FLUX/COMMAND

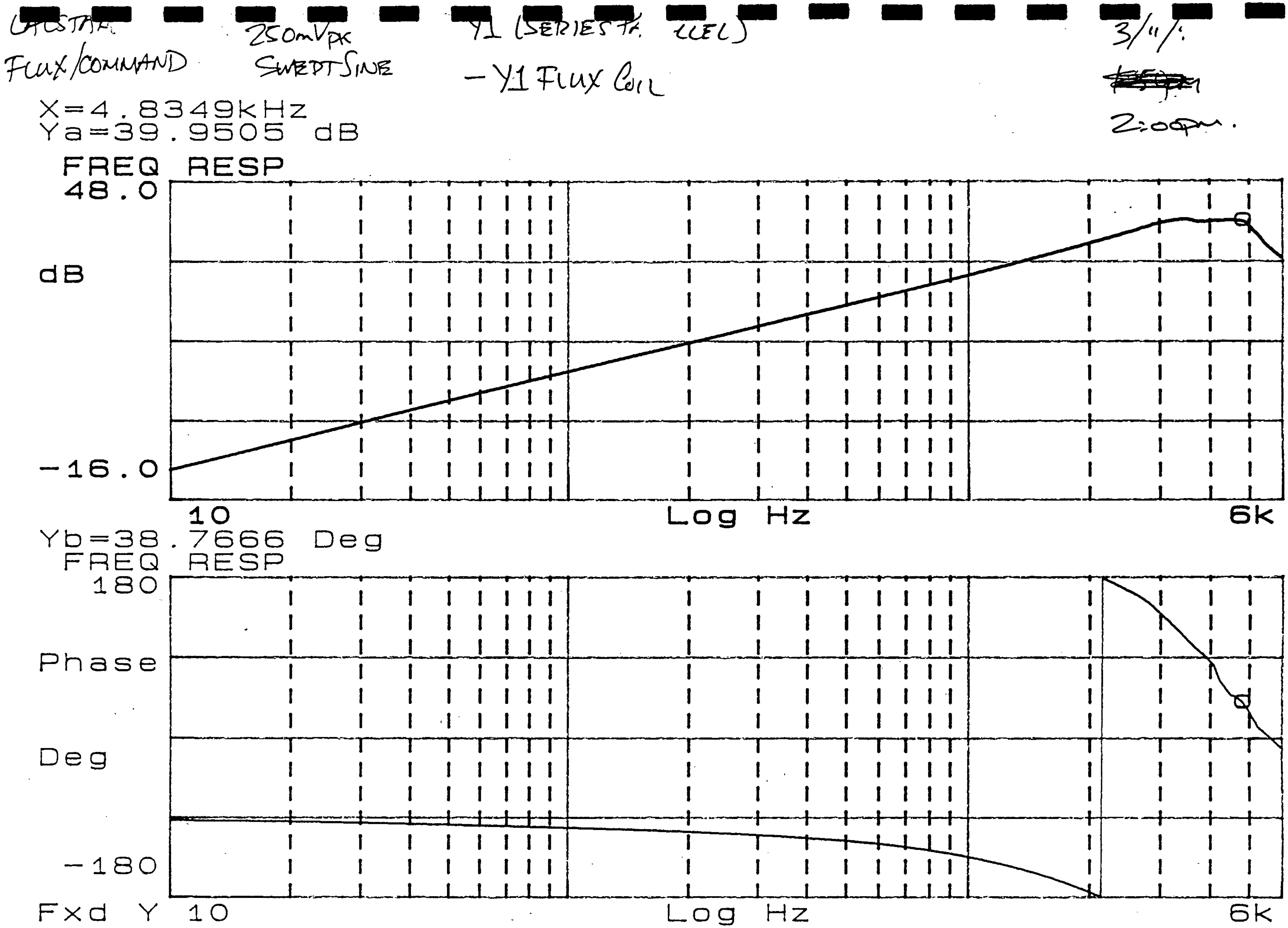
350mVpk
SWEPT SINE

Y1 (SERIES PARALLEL)
~Y1 FLUX COIL

3/11/96
2:25pm



1B-5


FLUX/COMMAND
250mVpk
SWEPT SINE
Y1 (SERIES
- Y1 FLUX COIL
2:00pm.
X=4.8349kHz
Ya=39.9505 dB
FREQ RESP
48.0
dB
-16.0
10
Log Hz
6k
Yb=38.7666 Deg
FREQ RESP
180
Phase
Deg
-180
Fxd Y 10
Log Hz
6k

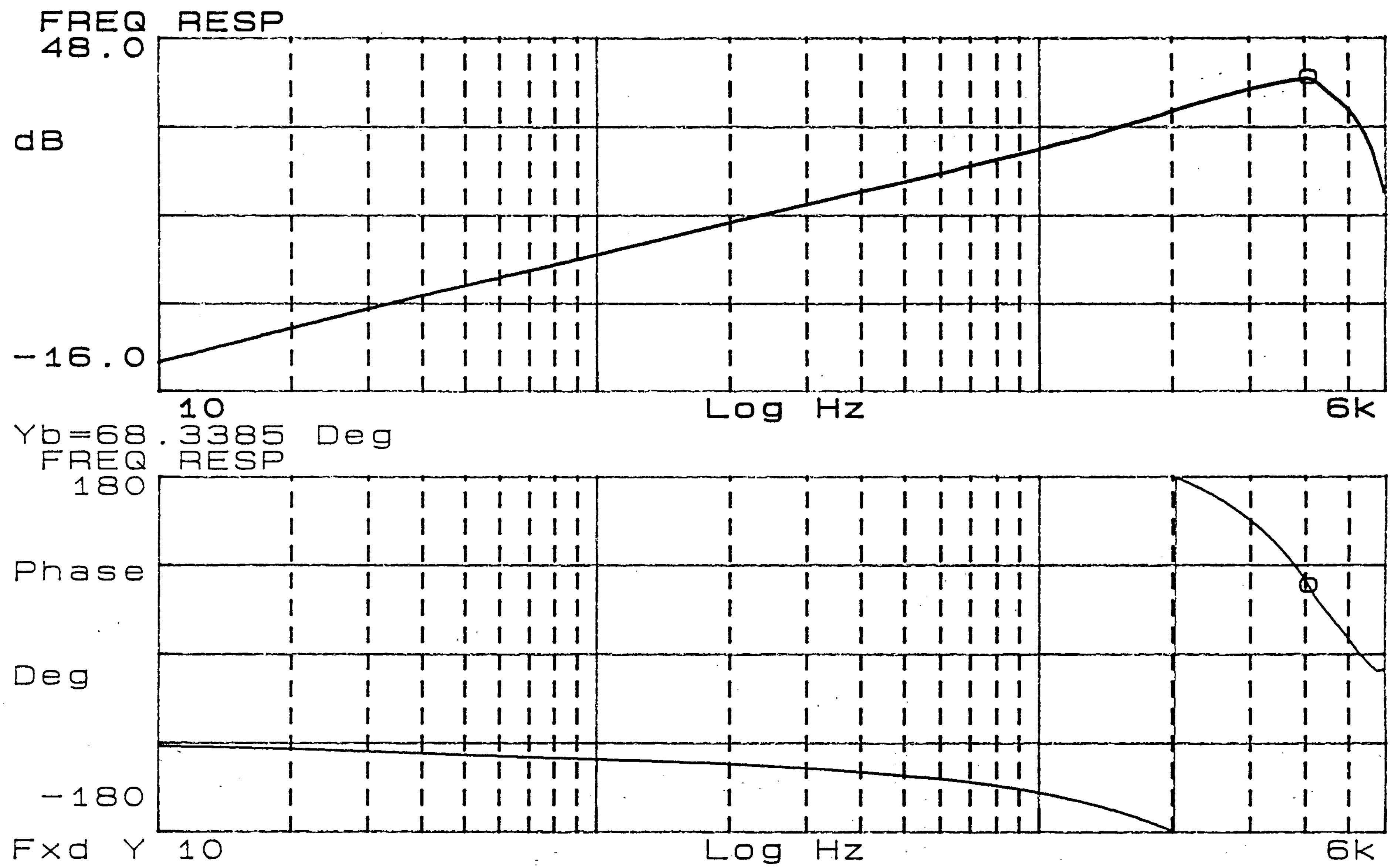
1B-6

GTESTH.

FLUX/COMMAND 100mVpk SWEPT SINE Y1 (SERIES PARALLEL) 3/11 1:50pm

X=4.0875kHz
Ya=40.8889 dB

-Y1 FLUX COIL



CASSTAR: FLUX / CURRENT

X2 OUTBOARD

+X FLUX COIL

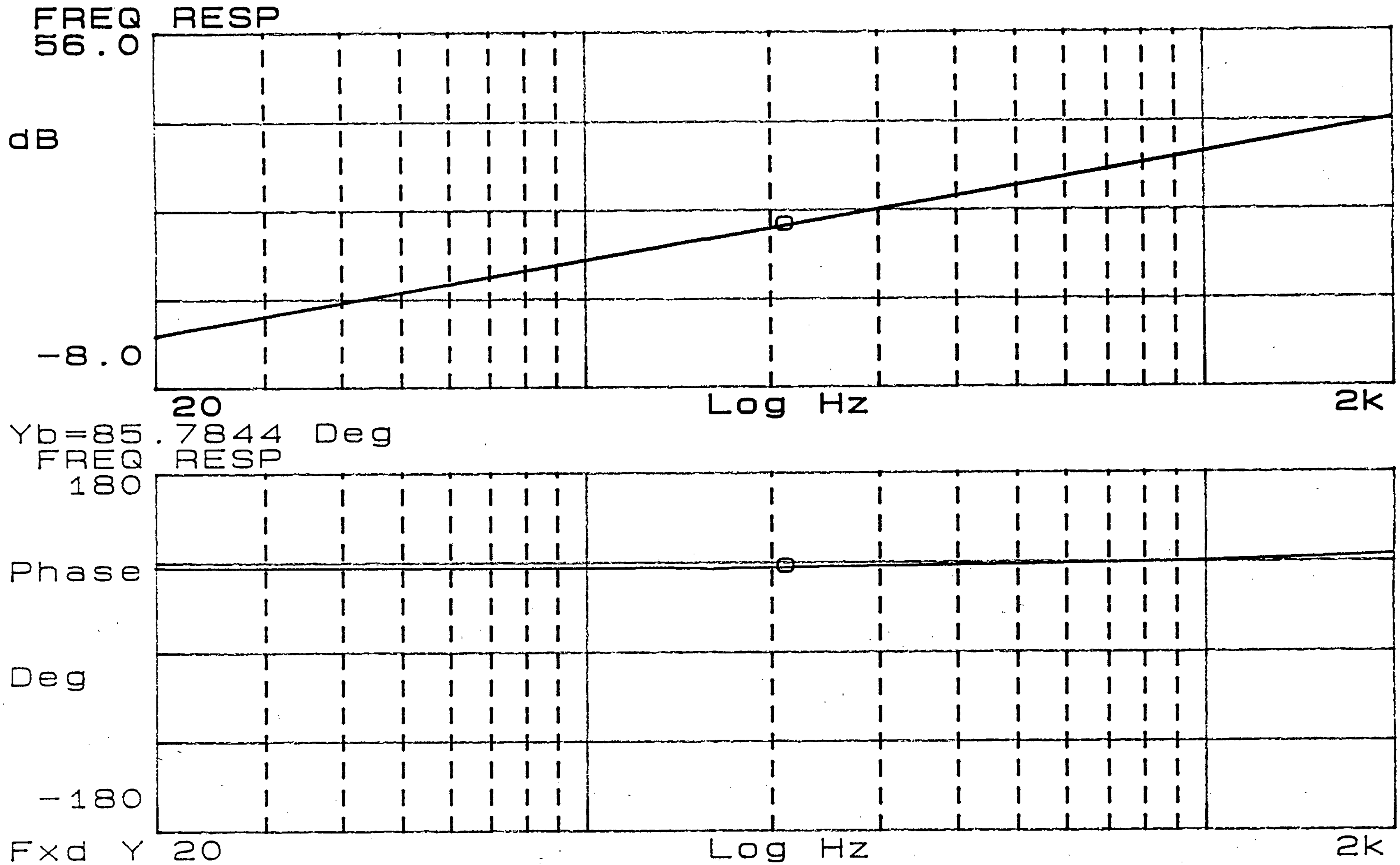
100 mV pk SWEPT SINE

3/ 8

11:20 am

X=211.85 Hz

Ya=21.213 dB



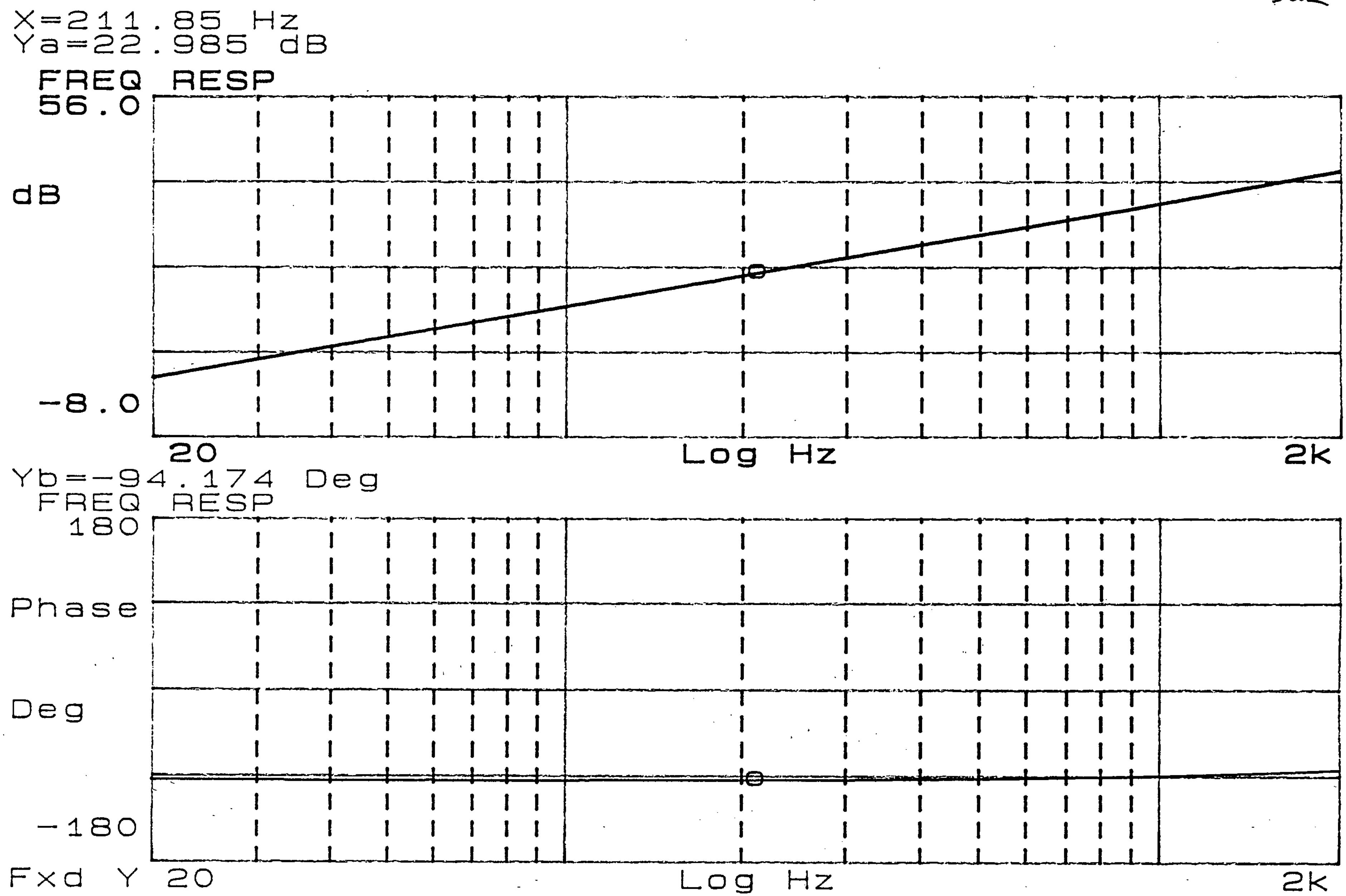
18-8

CALSTAR
FLUX/CURRENT

1/2 OUTBOARD
-1/2 FLUX COIL

100mVpk SWEPT SINE

3/ ,98
10:55am



CAESTAR]

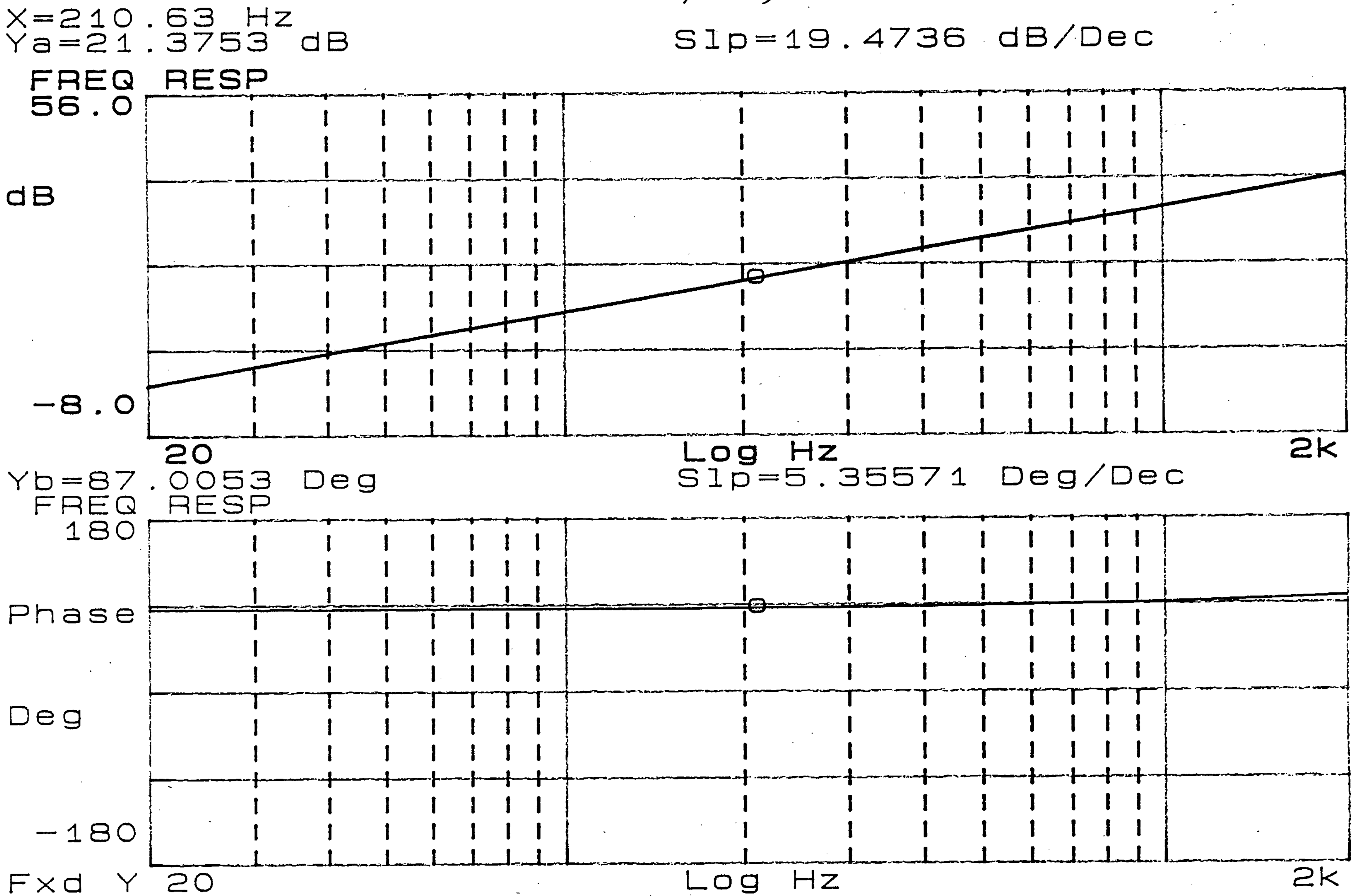
FLUX/CURRENT

Y2 OUTBOARD (ORNG/. .UE)

+Y2 FLUX COIL (ORANGE/WHITE)

100mVpk SWEPT SINE

10:25 am.



IB-10

CALSTART
FLUX / CURRENT

100mVpk SWEPT SINE

X1 C BOARD (YEL/BLK)
-X1 FLUX COIL (WHT/BLK)

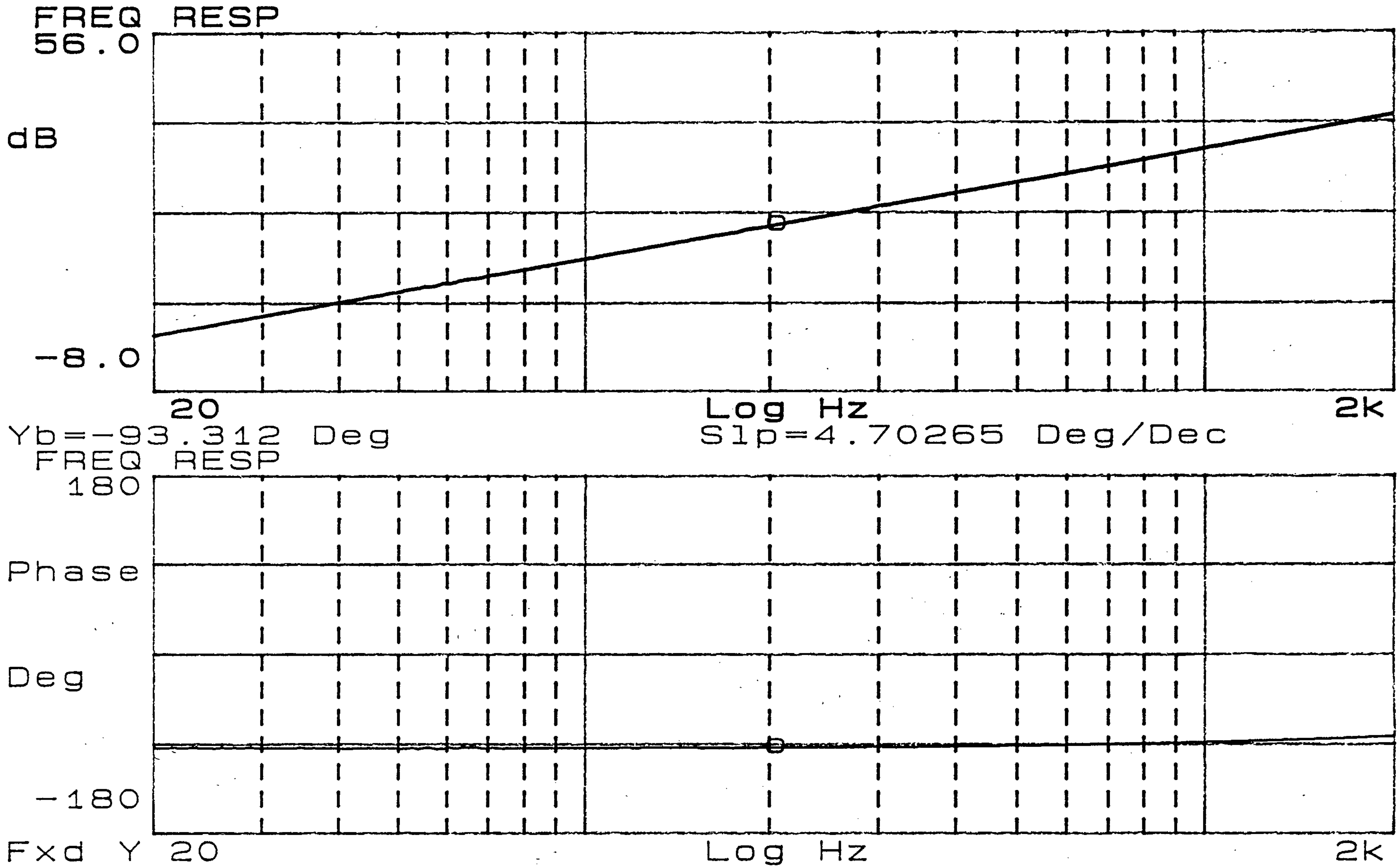
3/11/98
8:55am.

X=204.66 Hz
Ya=21.8677 dB

Slp=18.7282 dB/Dec

Yb=-93.312 Deg

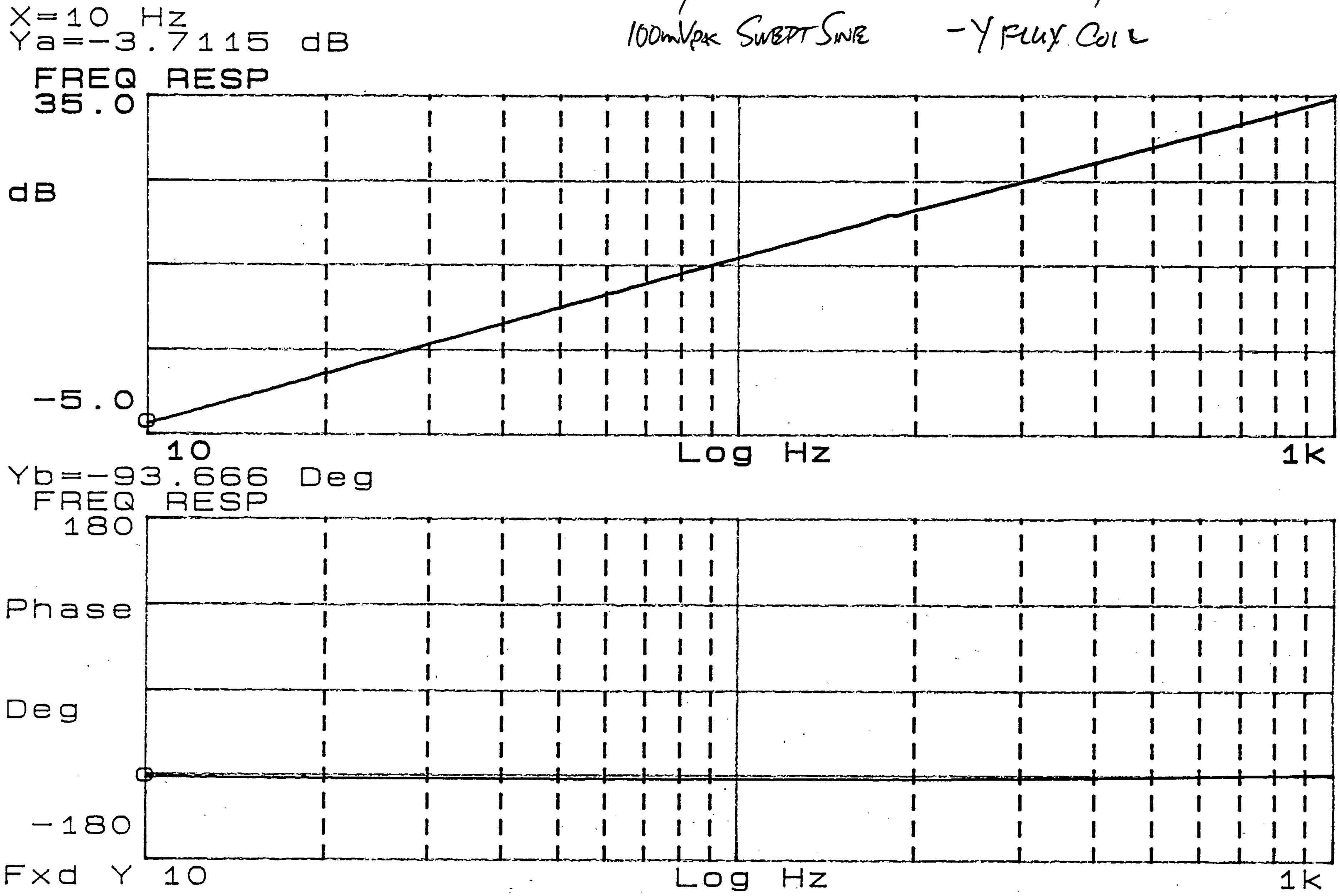
Slp=4.70265 Deg/Dec



Flux/Current 100mVpk Swept Sine

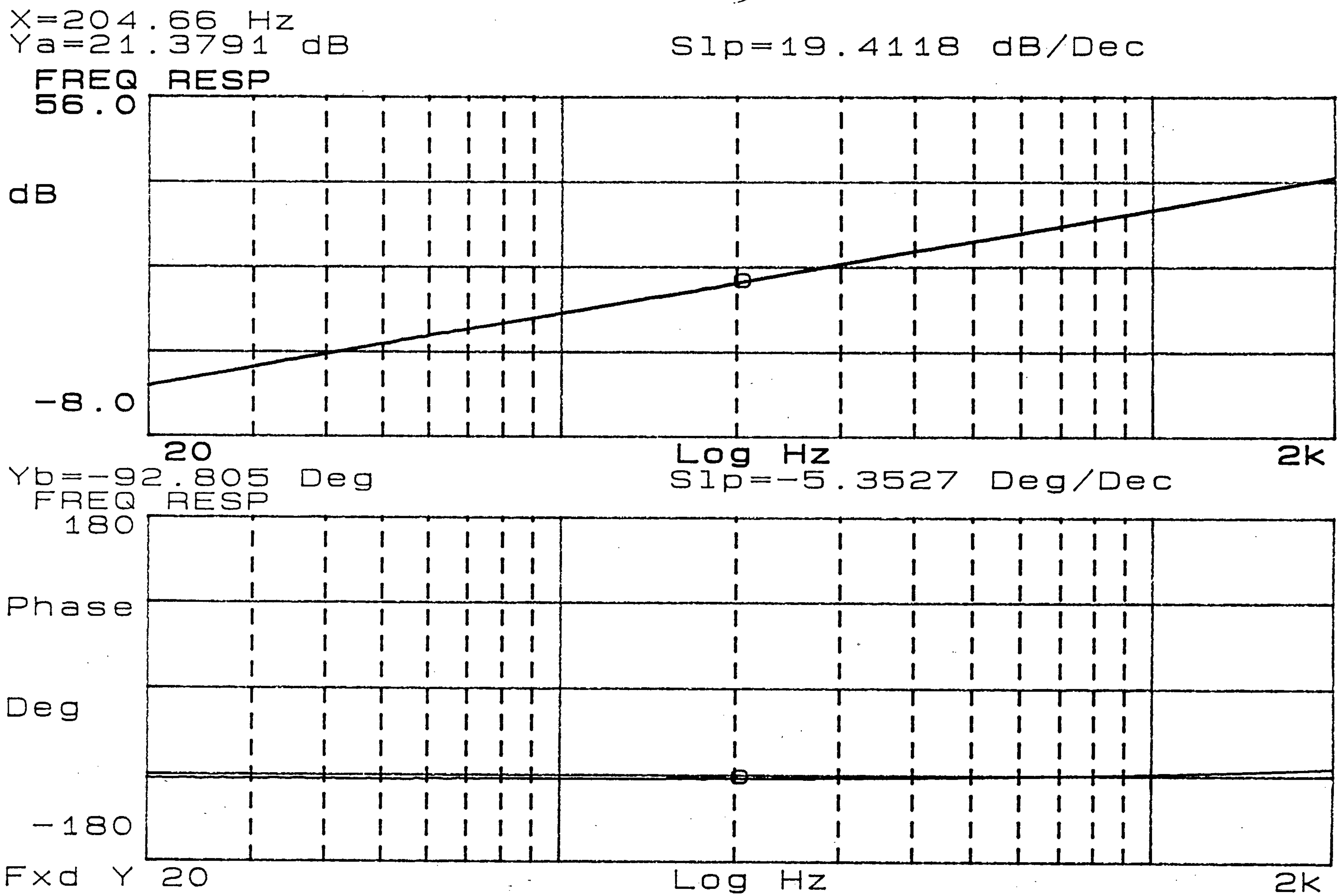
CALSTART Outboard Y1 -Y Flux Coil

3/10/98



1B-12

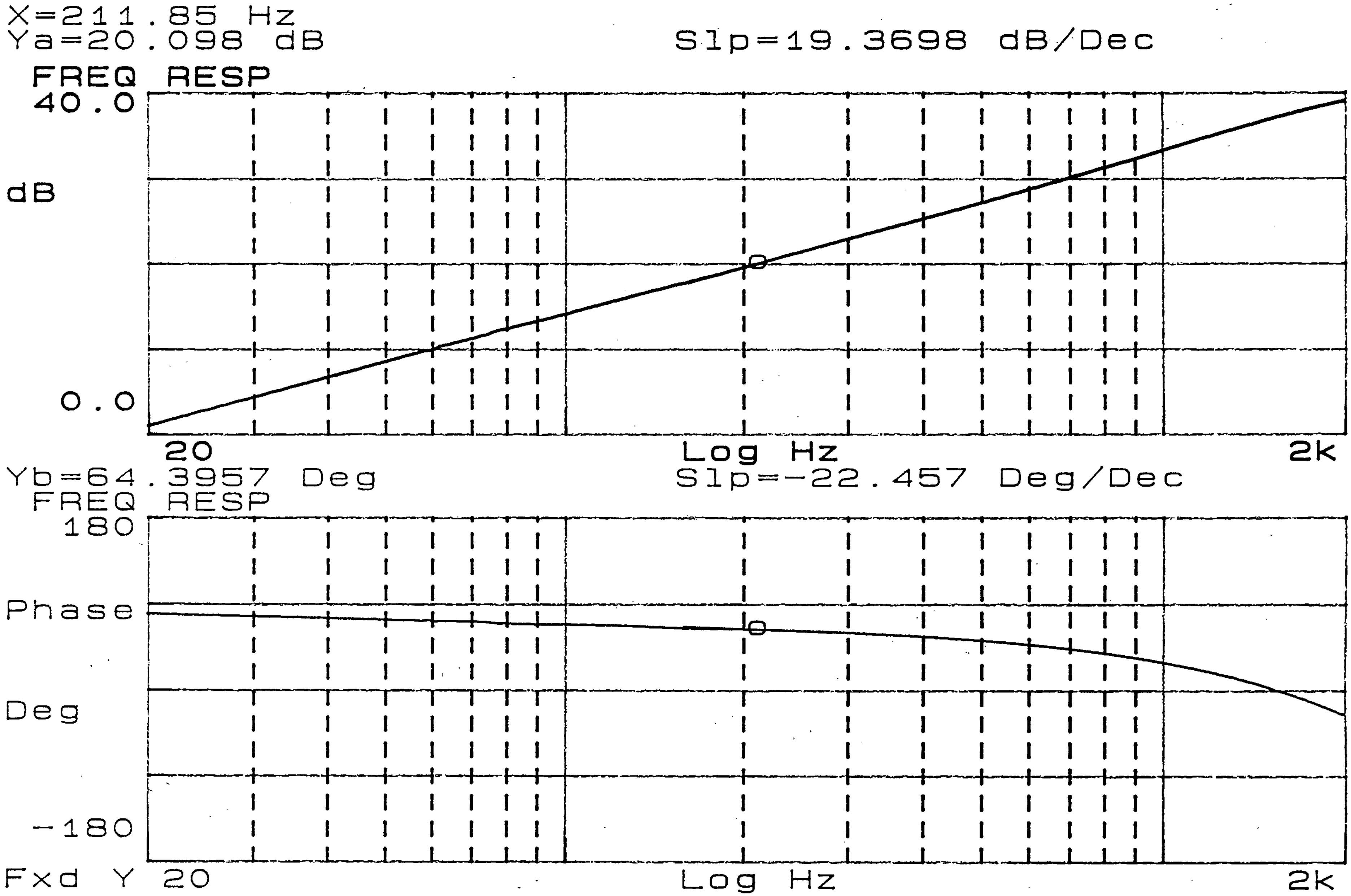
Y1 OUTBOARD (~~Red/Green~~ Orange/Blue)



Calstart

13-13

CALSTART FLUX/COMMAND X 2 OUTBOARD +X FLUX COIL 100mVpk SWEPT SINE. 3/11, 11:25 am.



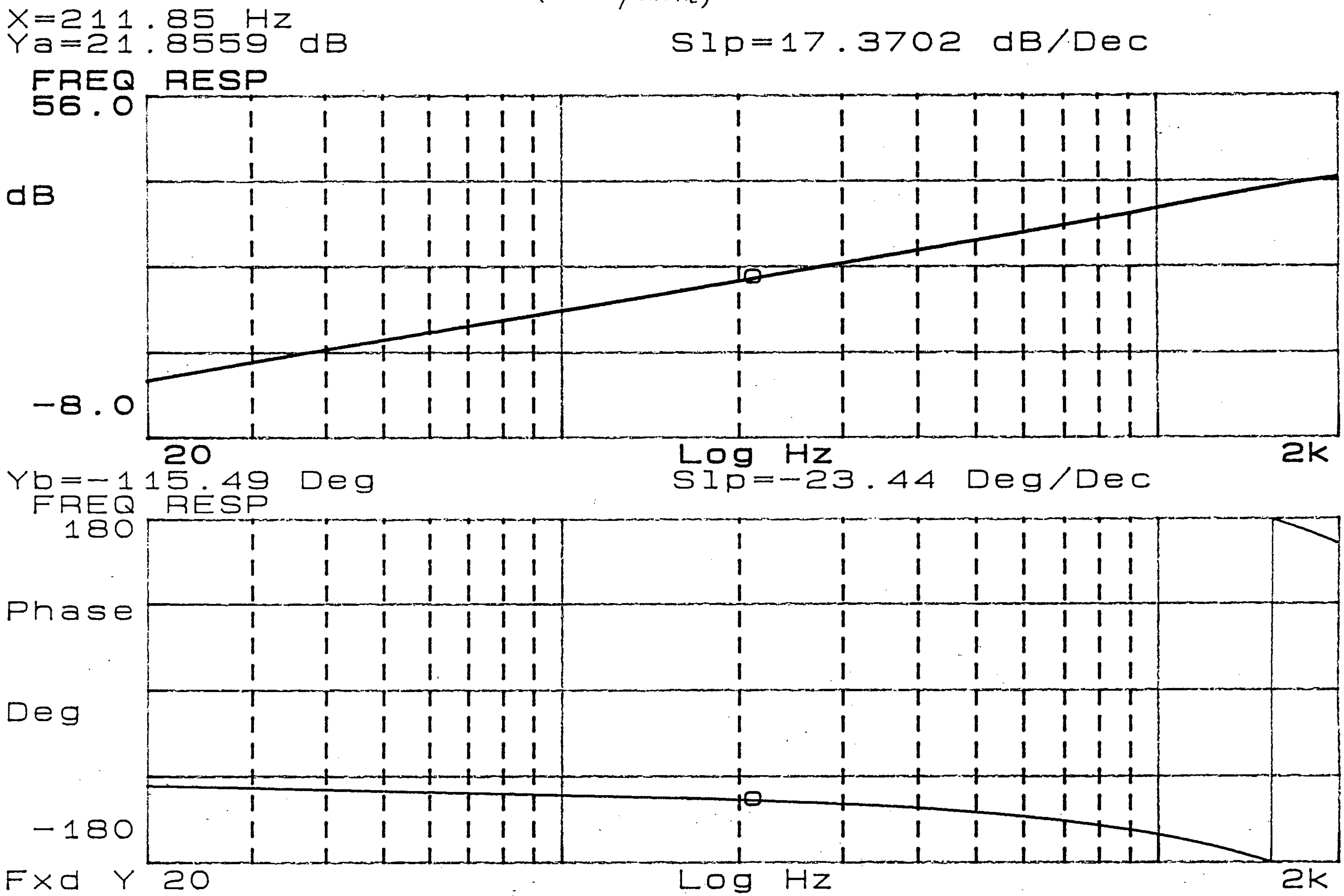
13-14

CALSTART
FLUX/COMMAND

Y2 OUTBOARD
-Y2 FLUX COIL (BLACK/WHITE)

100mVpk SWEPT SINE

3, /98
10:40am



1B-15

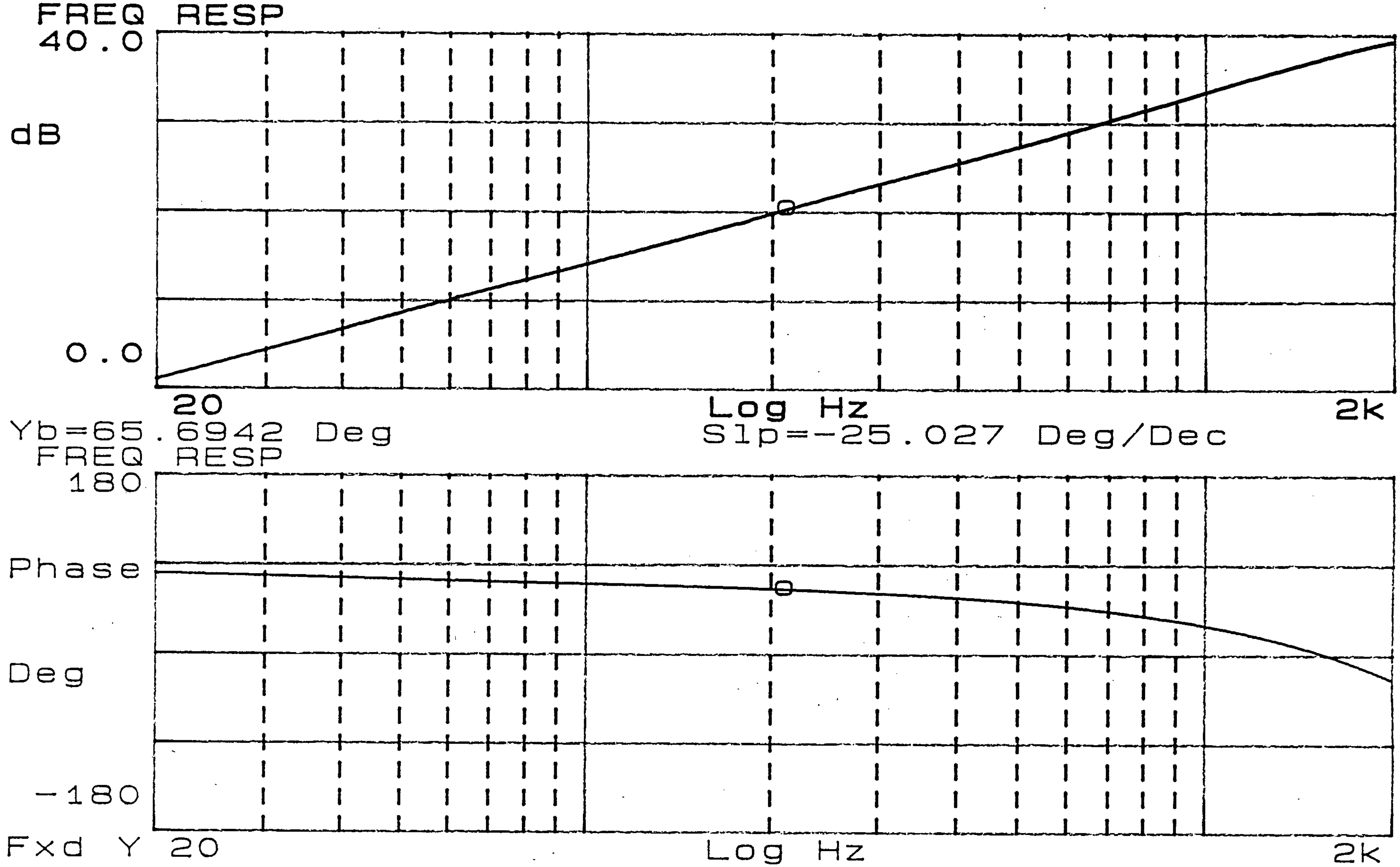
GESTALT FLUX/COMMAND

+Y2 FLUX COIL

100mVpk SWEPT SINE

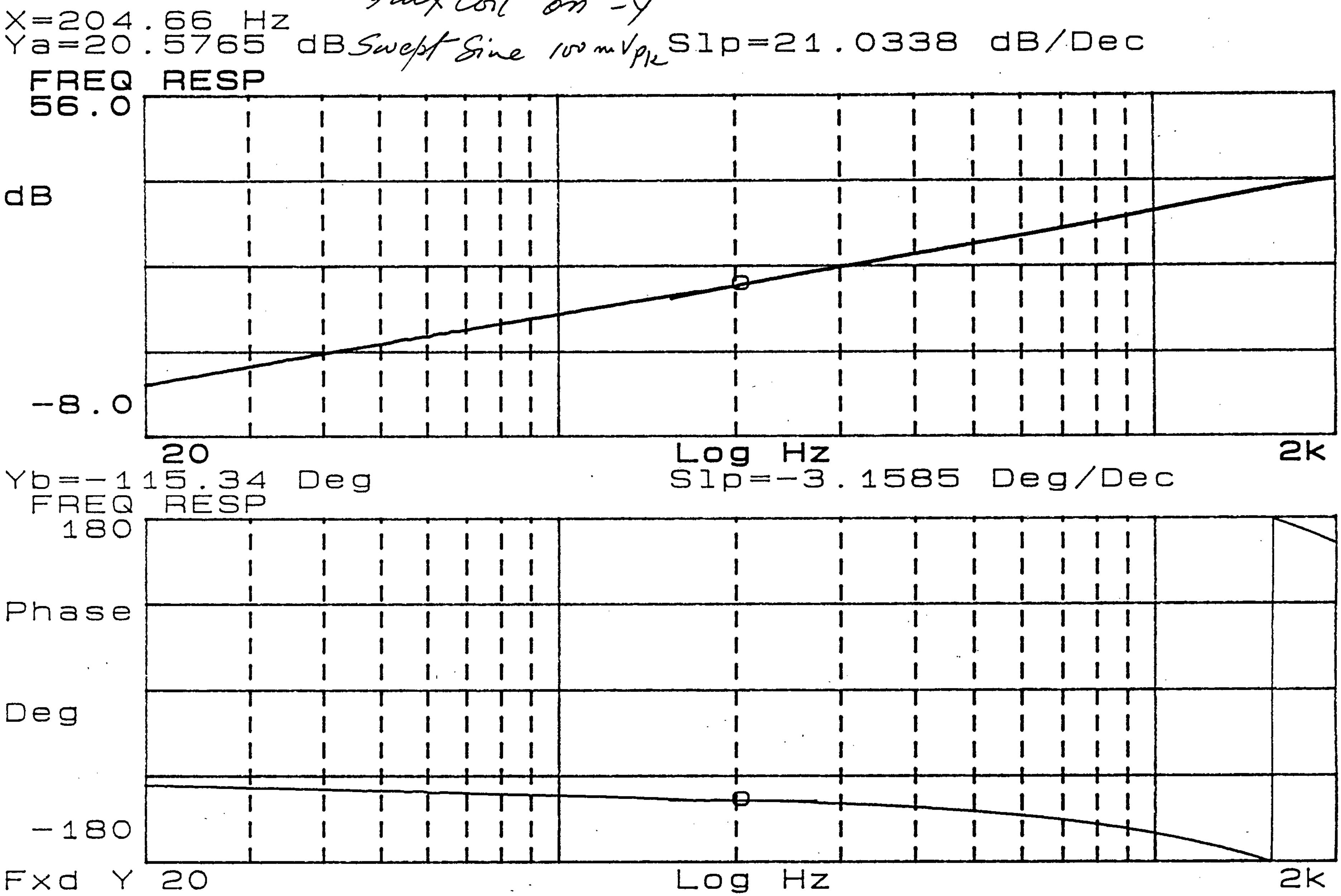
3/1 :8 10:33 am

X=210.63 Hz
Ya=20.3032 dB
Slp=18.761 dB/Dec



1B-16

Y1 outboard (Orange/Blue yellow)
Flux Coil on -Y



calstart

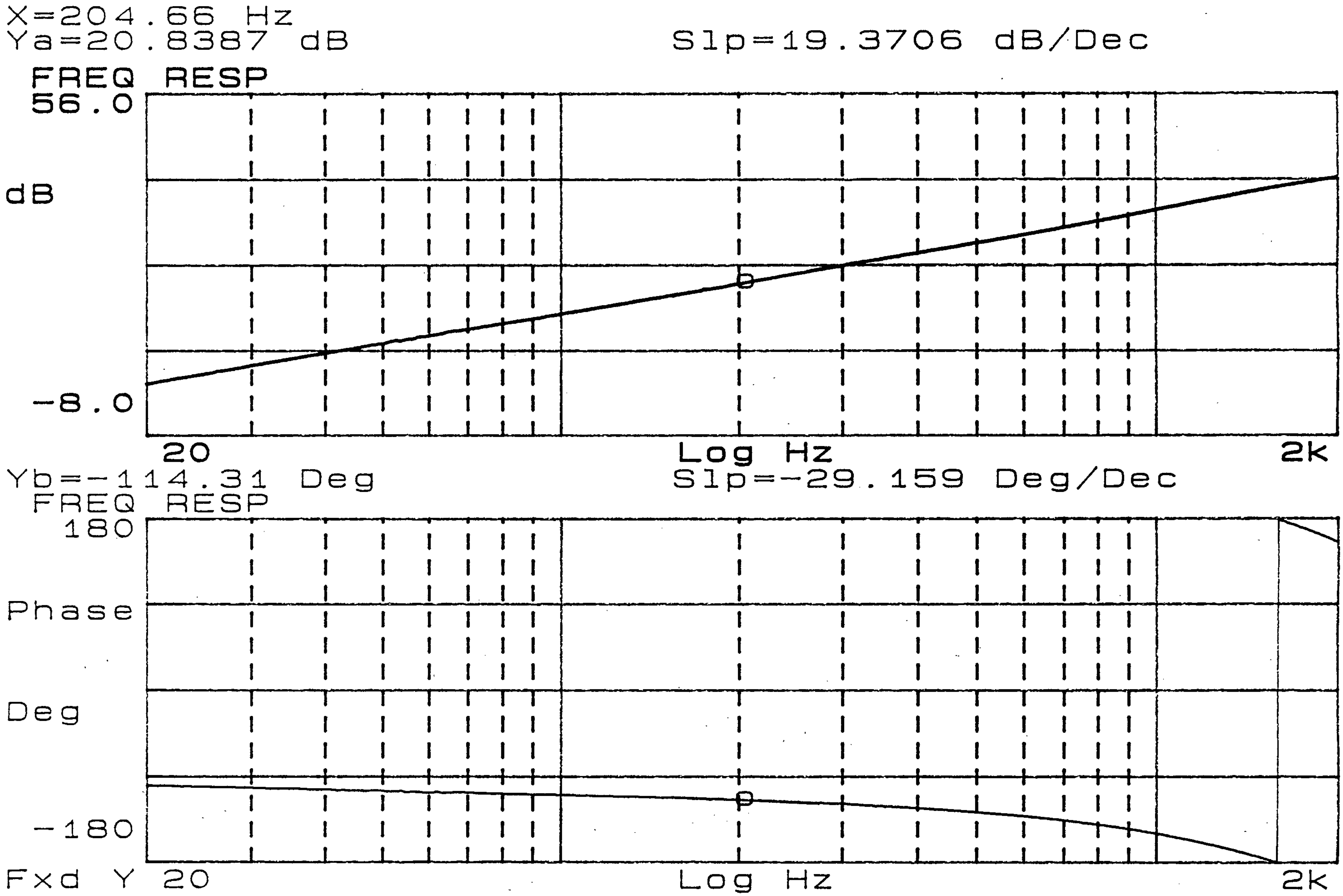
1.B-17

CALSTAR FLUX/COMMAND

-X1 FLUX COIL (BLK/WHT)
+X1 OUTBOARD (YEL/BLK)

100mVpk SWEPT SINE

3, '98
8:47 am



1B-18

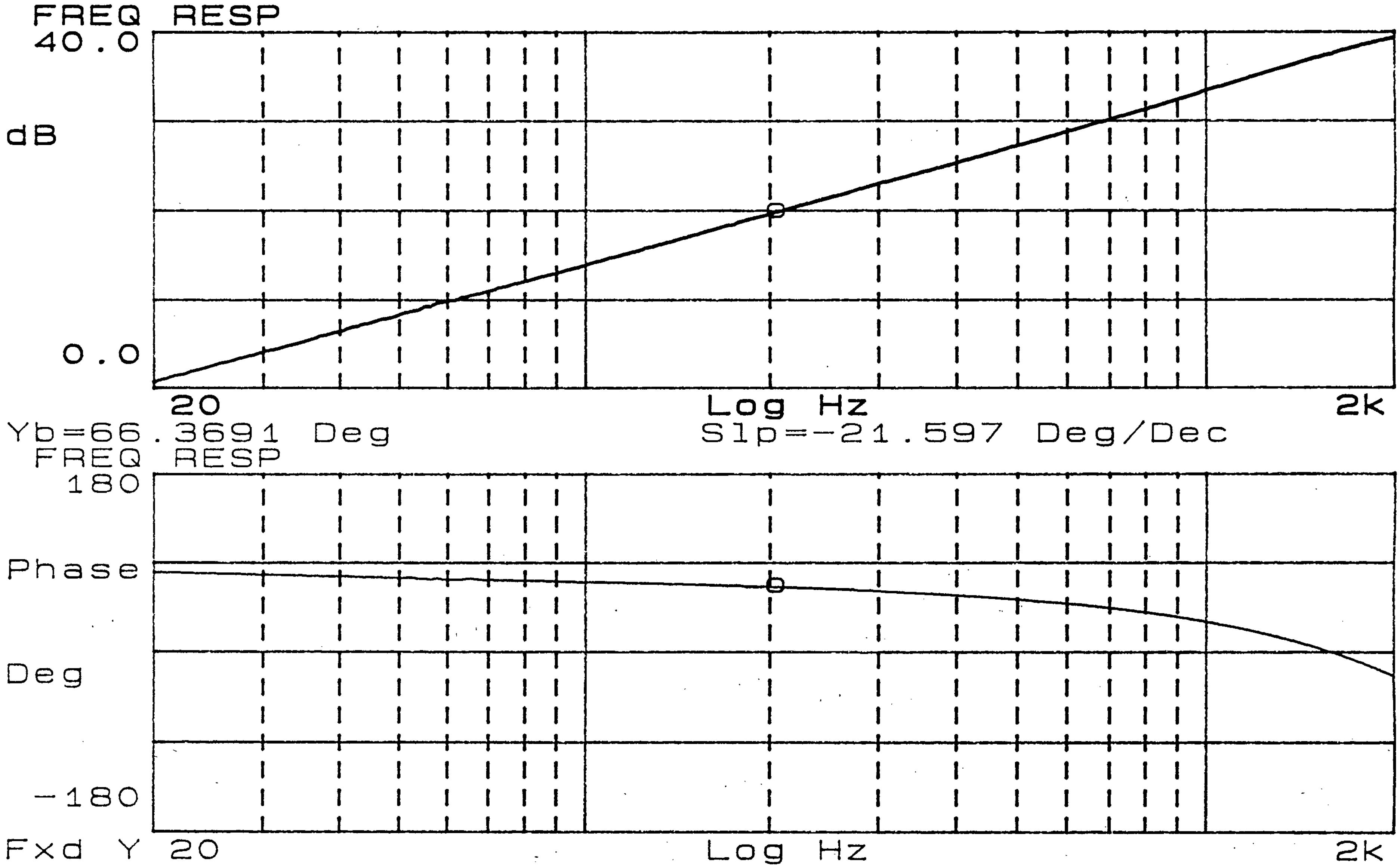
FLUX / COMMAND 100mVpk SWEPT SINE +X1 OUTBOARD (BLK/YEL) +X1 FLUX COIL (WHT/YEL) 3/ 1/98 8:40am

X=204.66 Hz
Ya=19.8469 dB

Slp=18.526 dB/Dec

Yb=66.3691 Deg

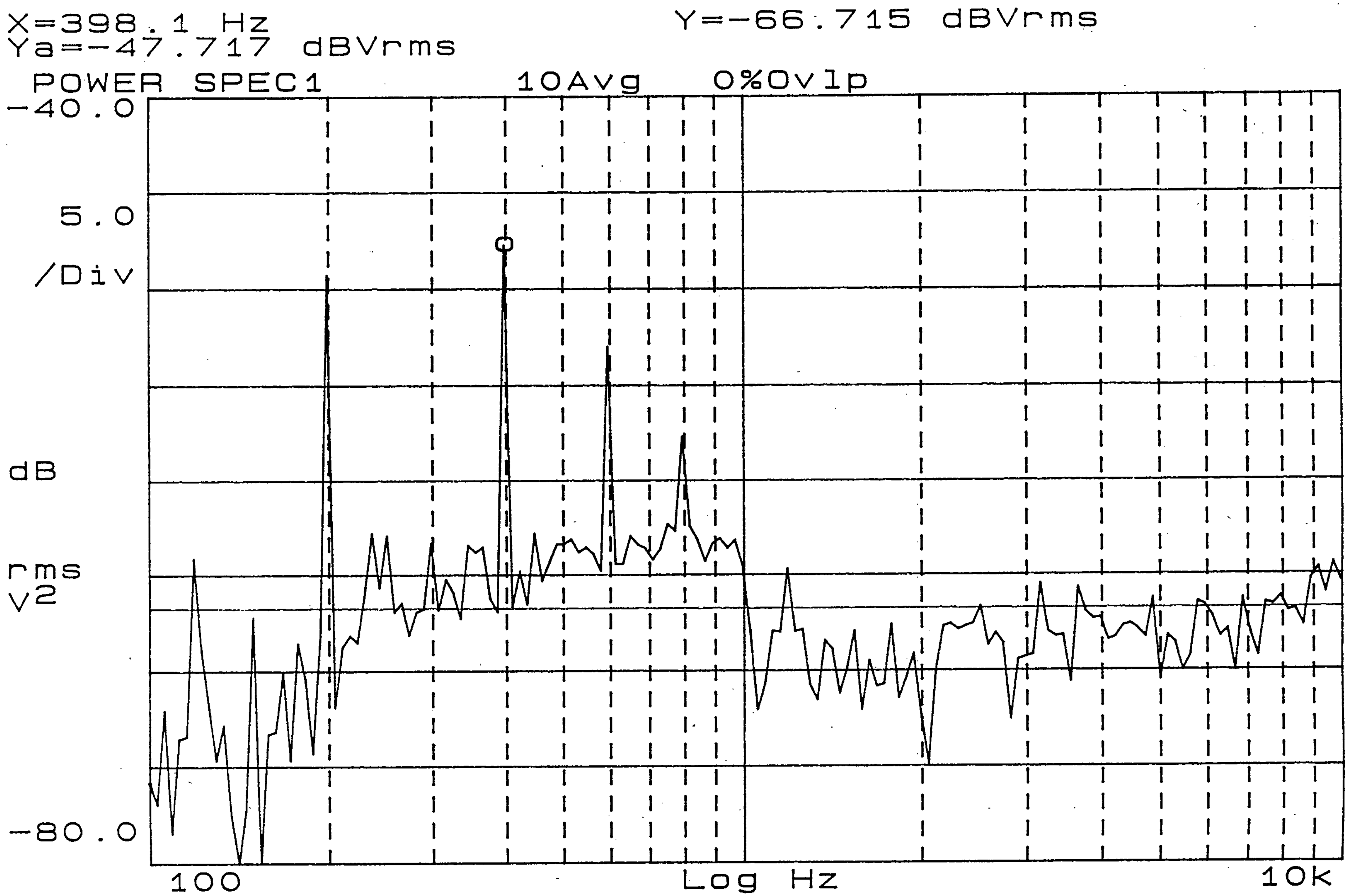
Slp=-21.597 Deg/Dec



1B-19.

APPENDIX 1C

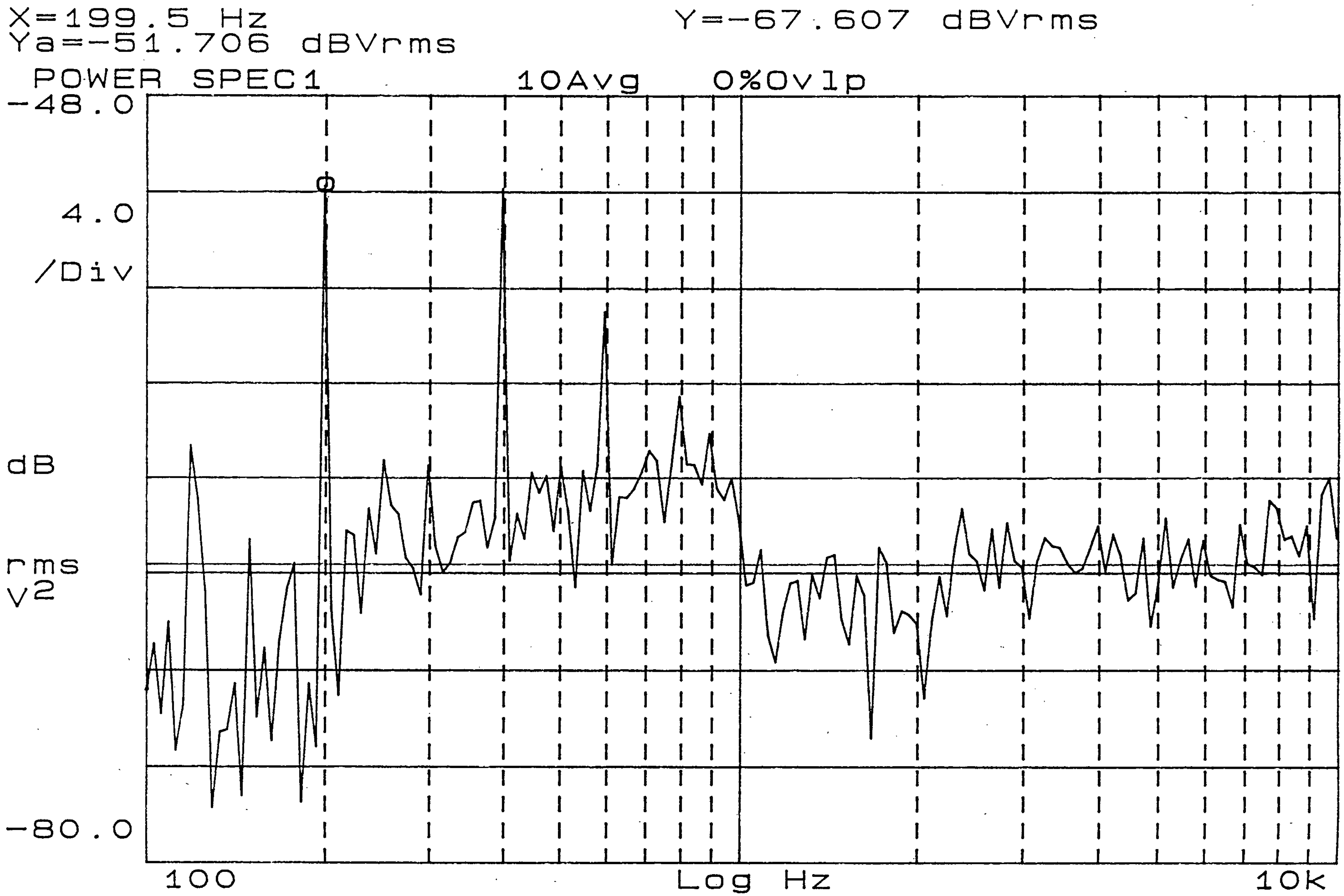
3/18/98



CALSTART

le-1

PSD: ch-3 (TPKBX) 3/18/1998

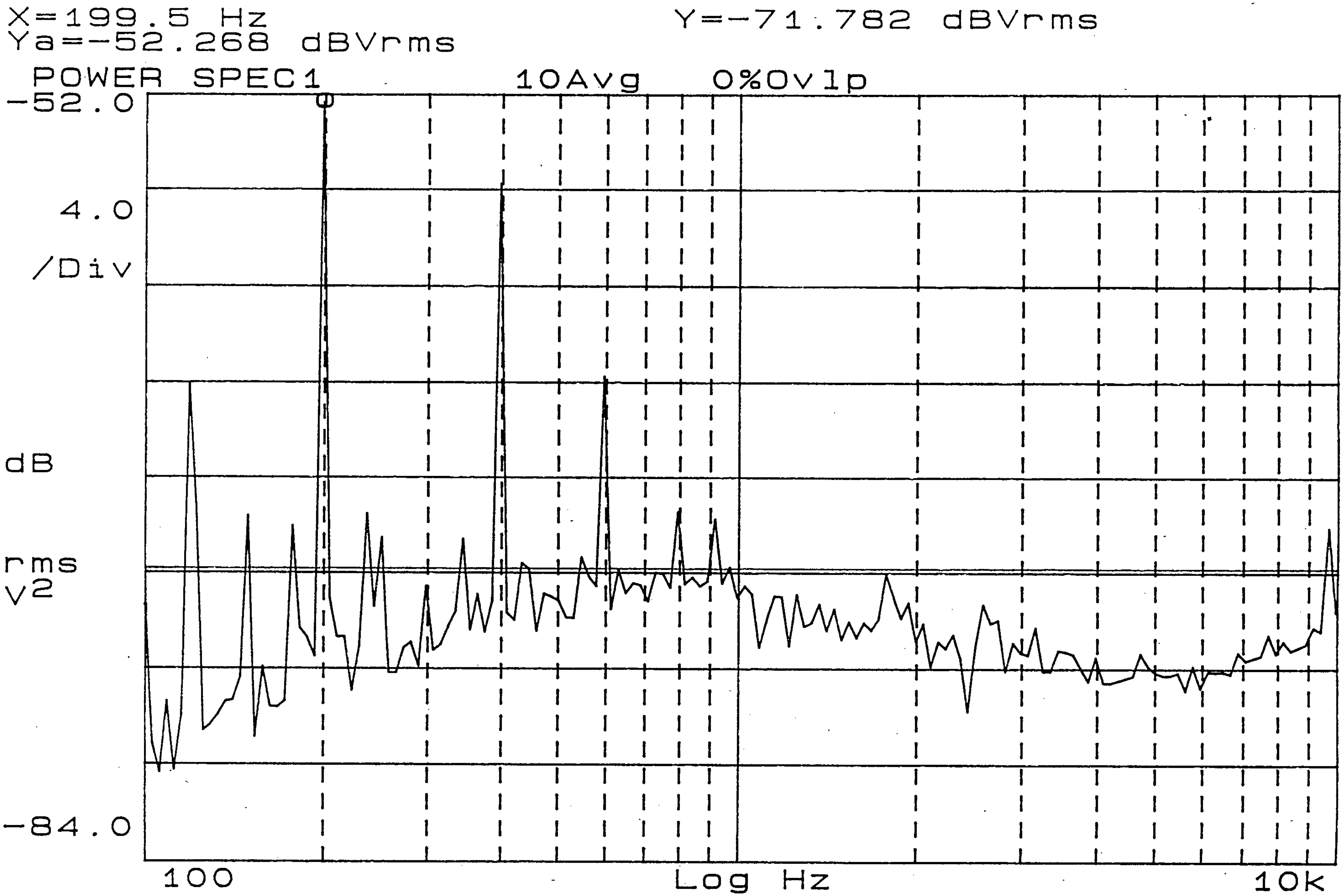


CALSTART

1C-2

PSD: ch2 (TPKA2)

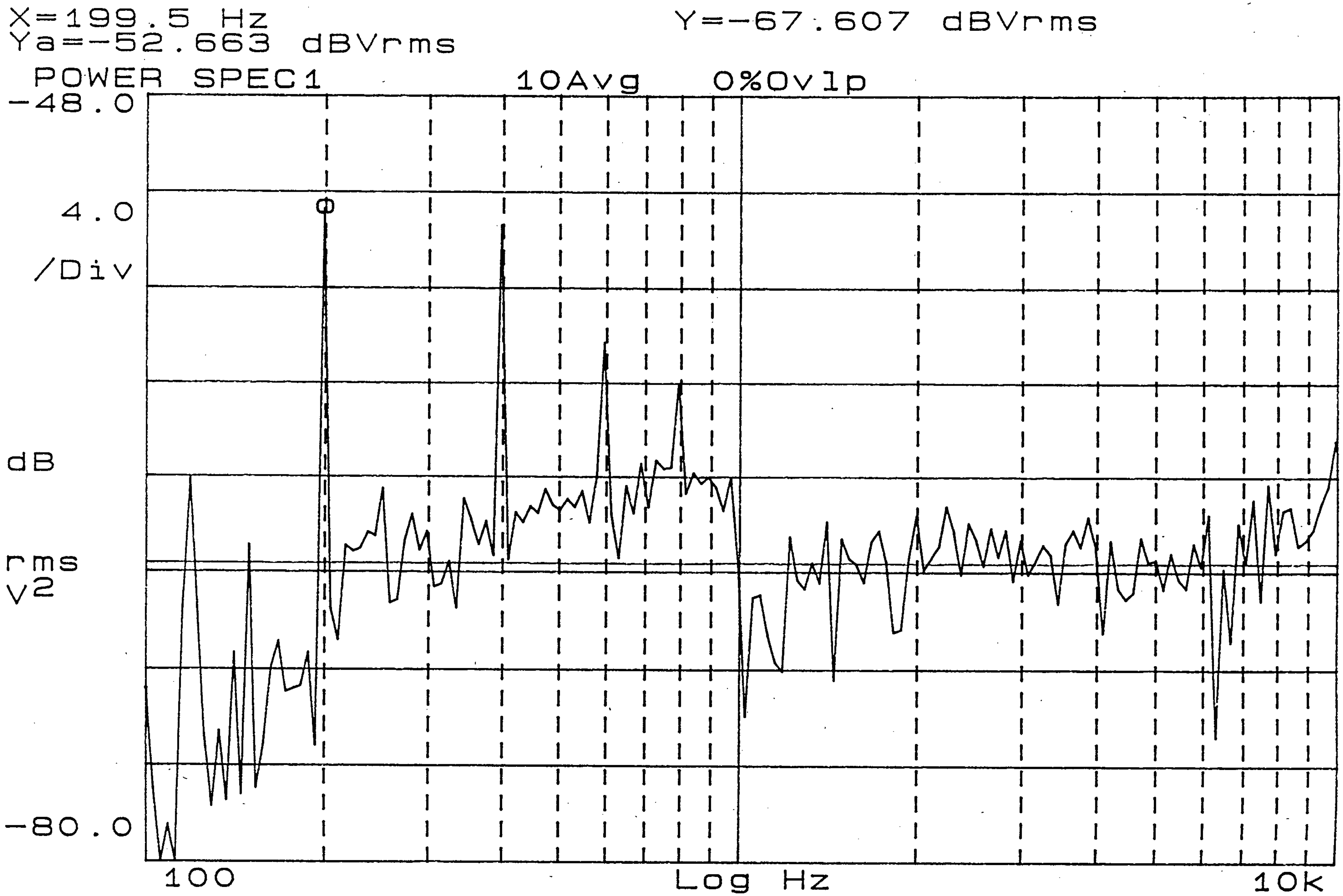
3268198



CACSTART

1c-3

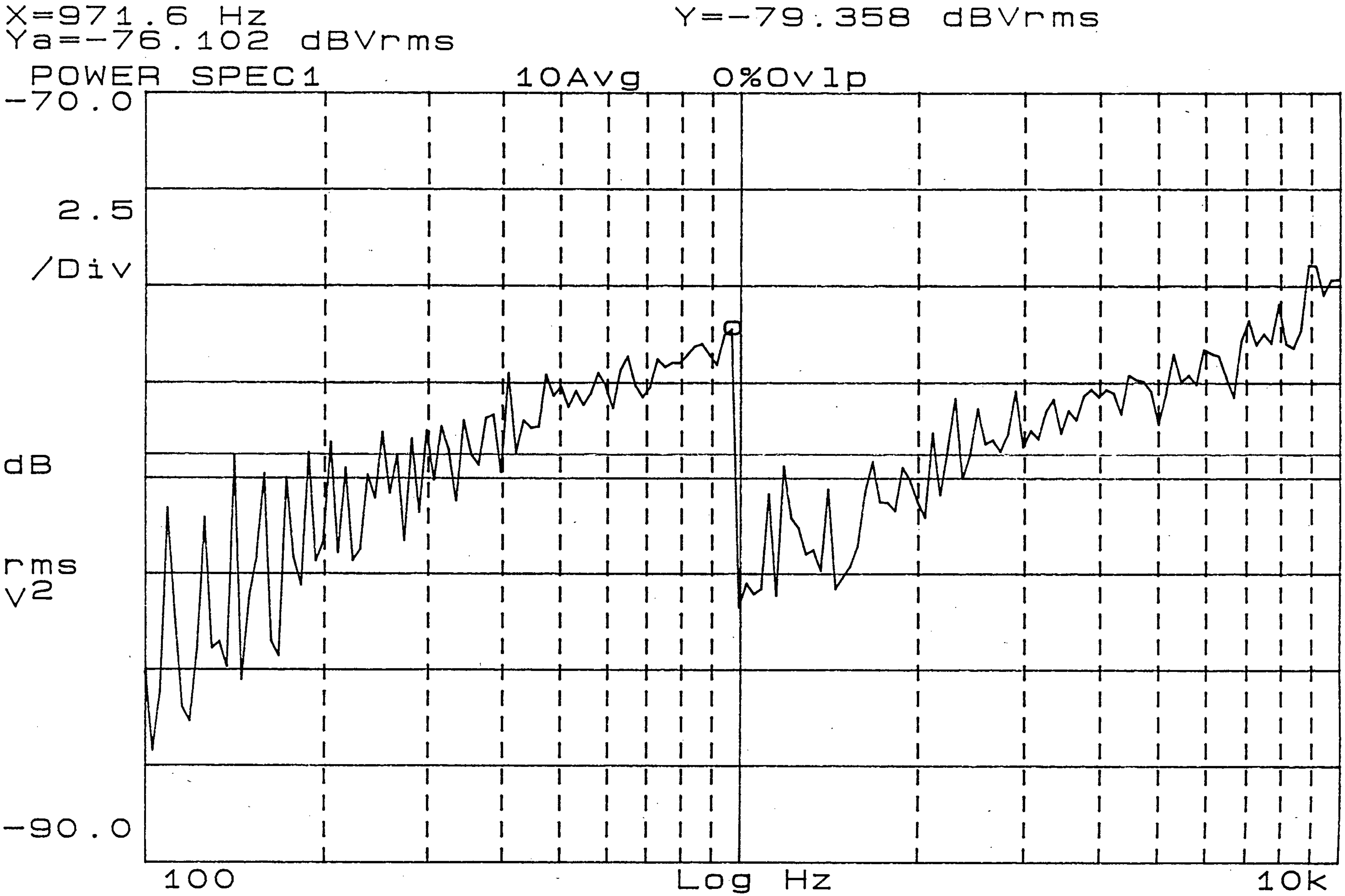
PSD: Ch. 4 (TPKB2)



CALSTART

1c-4

PSD: Cables shorted 3/18/98



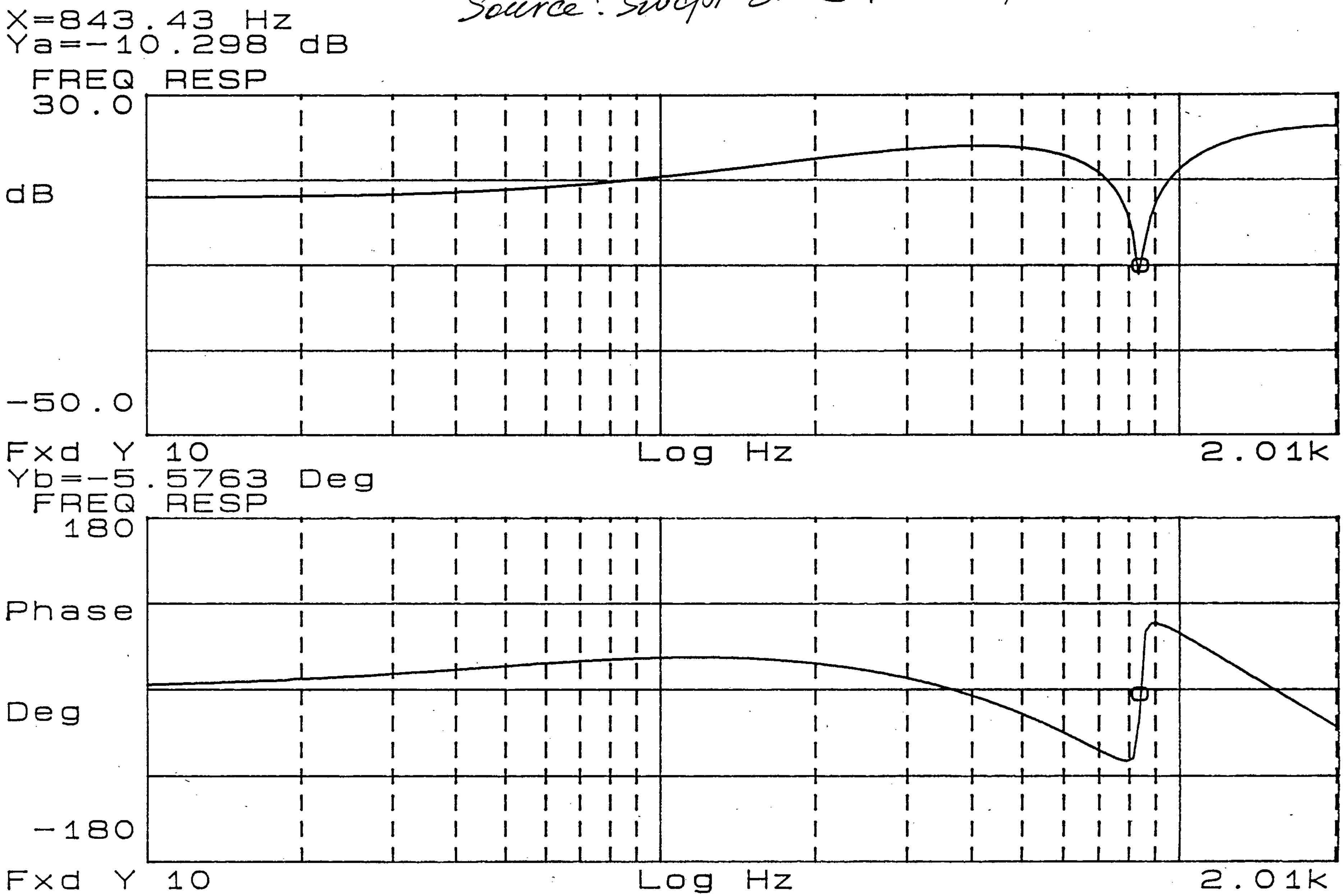
1e-5

APPENDIX 1D

DSA FILE: CSS
CODE: CSR5.DSP

Ch-1
Comp. XFR FN
Source: Swept Sine 100 mV pk

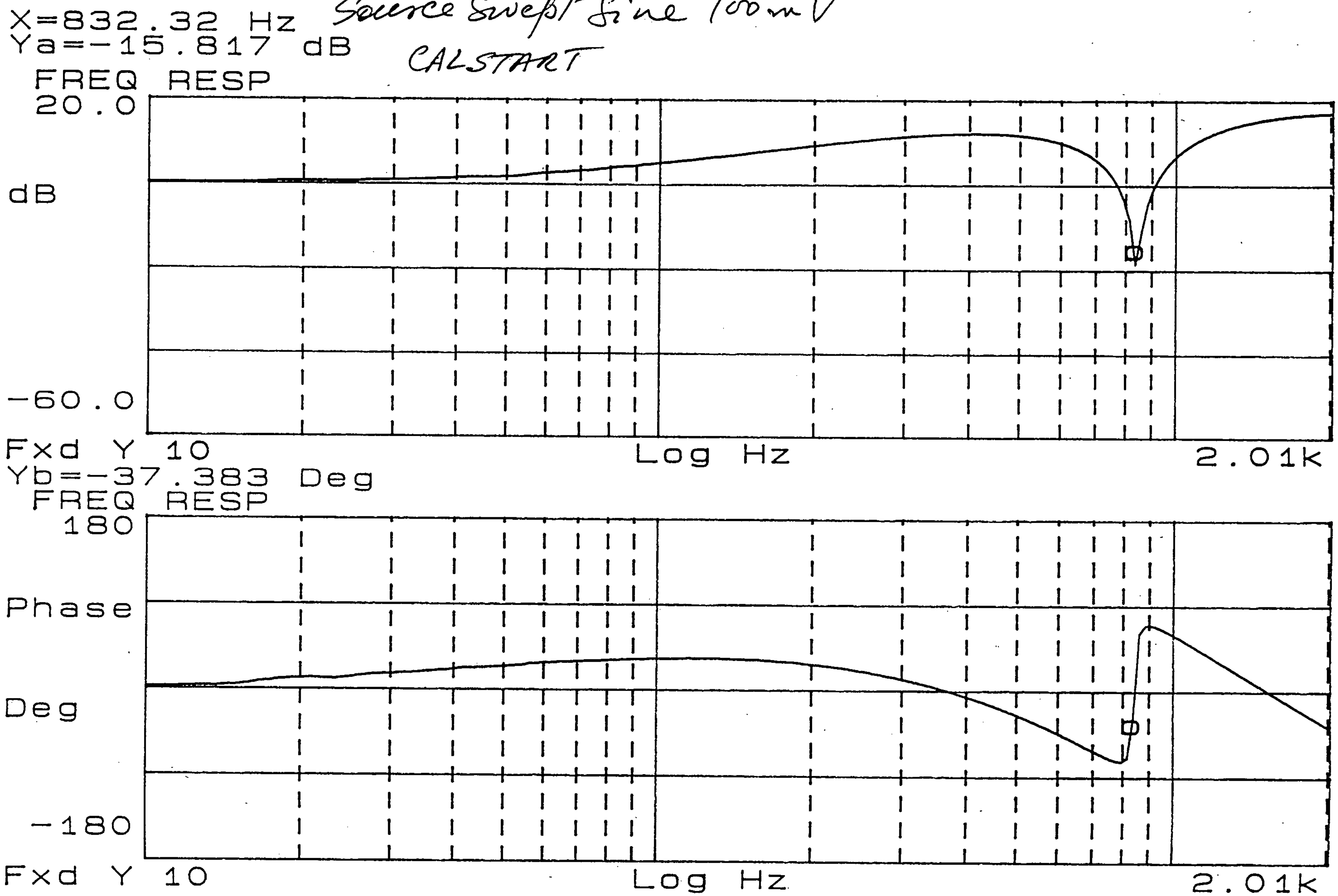
3/17/98



CALSTART

10-1

Device: CSS   Ch-2   3/17/98
Code: CSRS.DSP   Comp. XFR Fnl
Source Swept Sine 100mV
CALSTART



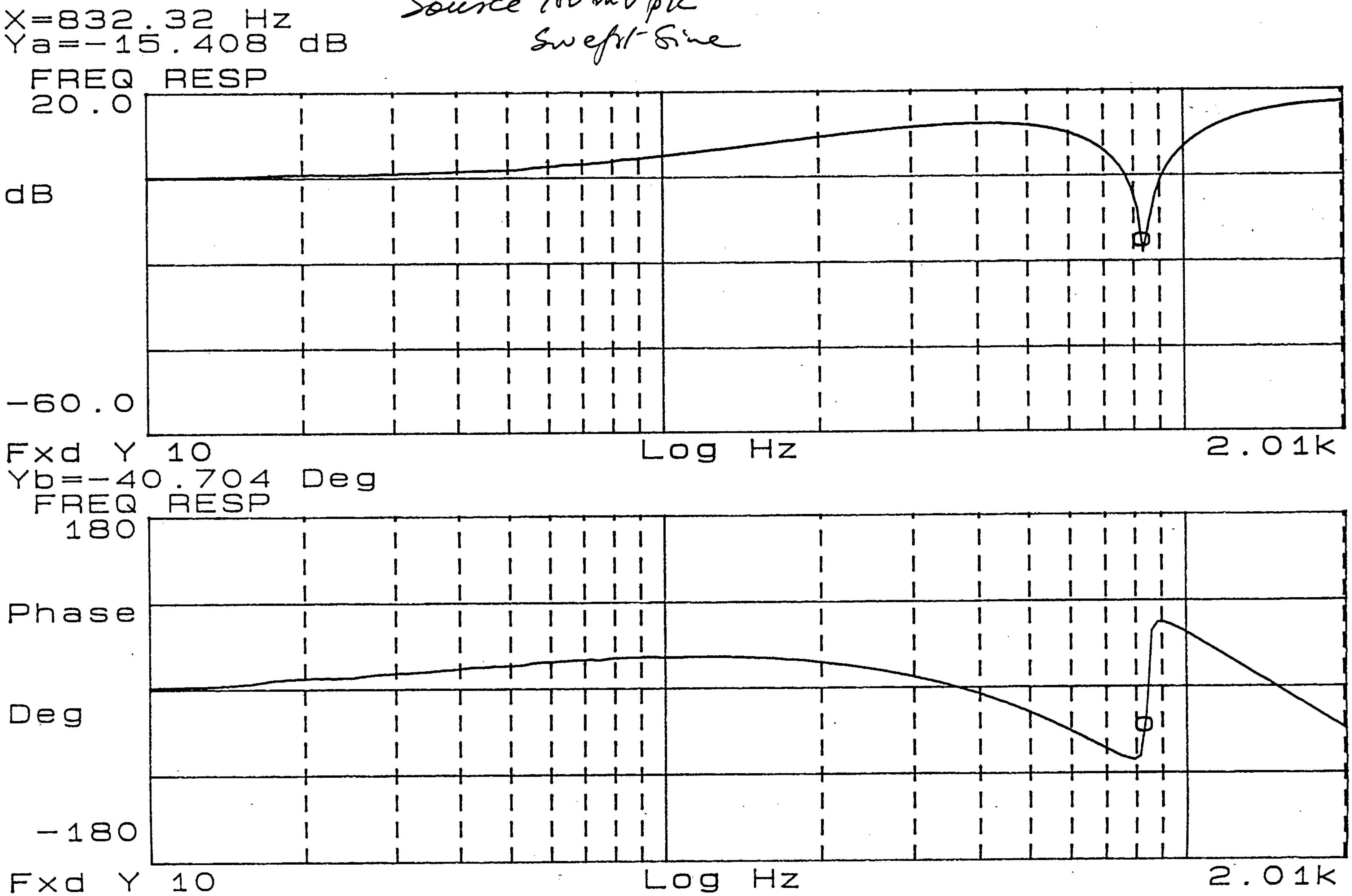
1D-2

File! CSS Ch-3 3/17/98

CODE! CSRS.DSP Comp XFR FN

Source 100 mVpk

Swept Sine



CAL START

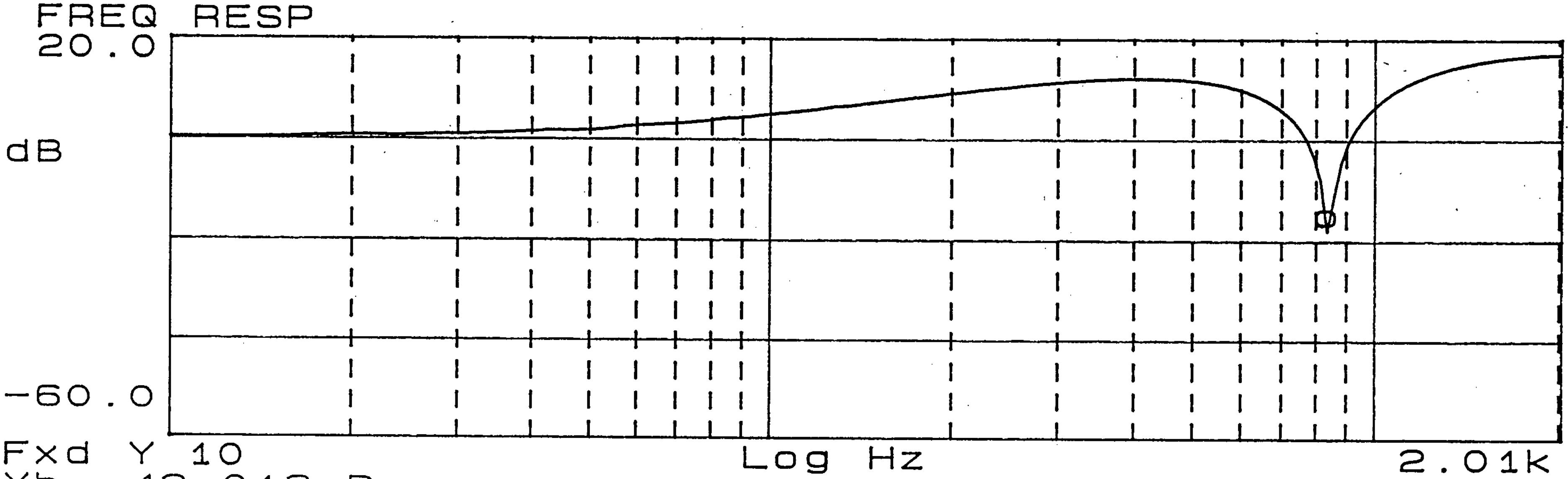
1D-3

DSN File: CS5
Code: CSR5.DSP

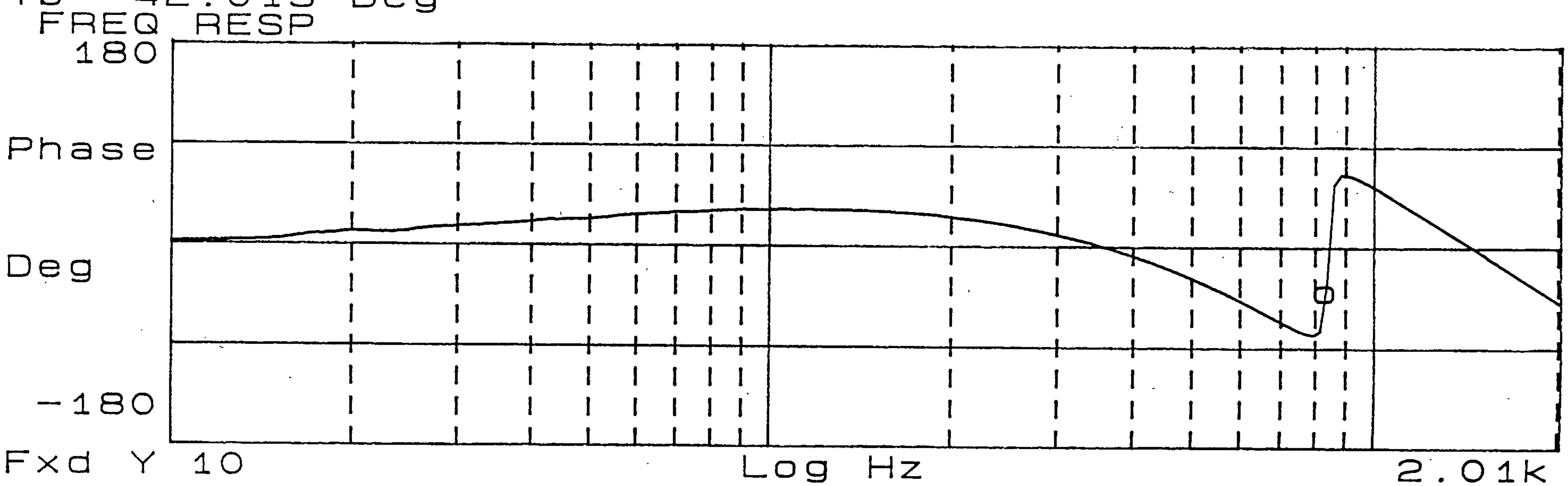
LW-4
Comp. XFR FN
Source swept sine/100 mV

2/11/1998

X=832.32 Hz
Ya=-15.467 dB



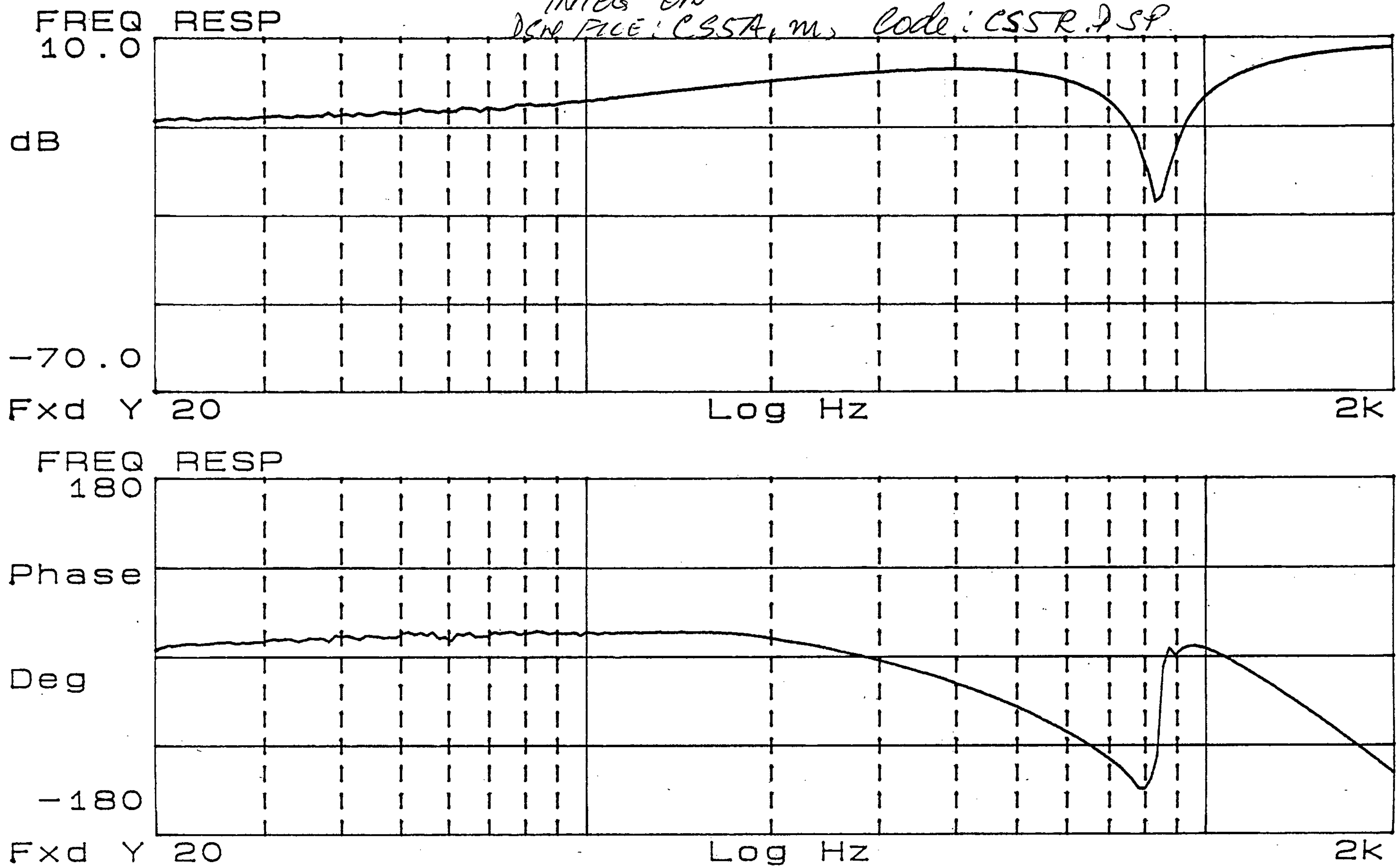
Yb=-42.013 Deg



CAL START

ID-4

XI: Comp.* XFR FN (B/A) B= [illegible] 3/24/98
A = ERROR X1
Source: Swept Sine 100 mV PK Sig @ X1 Bias
INTEG ON
DSN FILE: CS5A.m; Code: CS5R.DSP

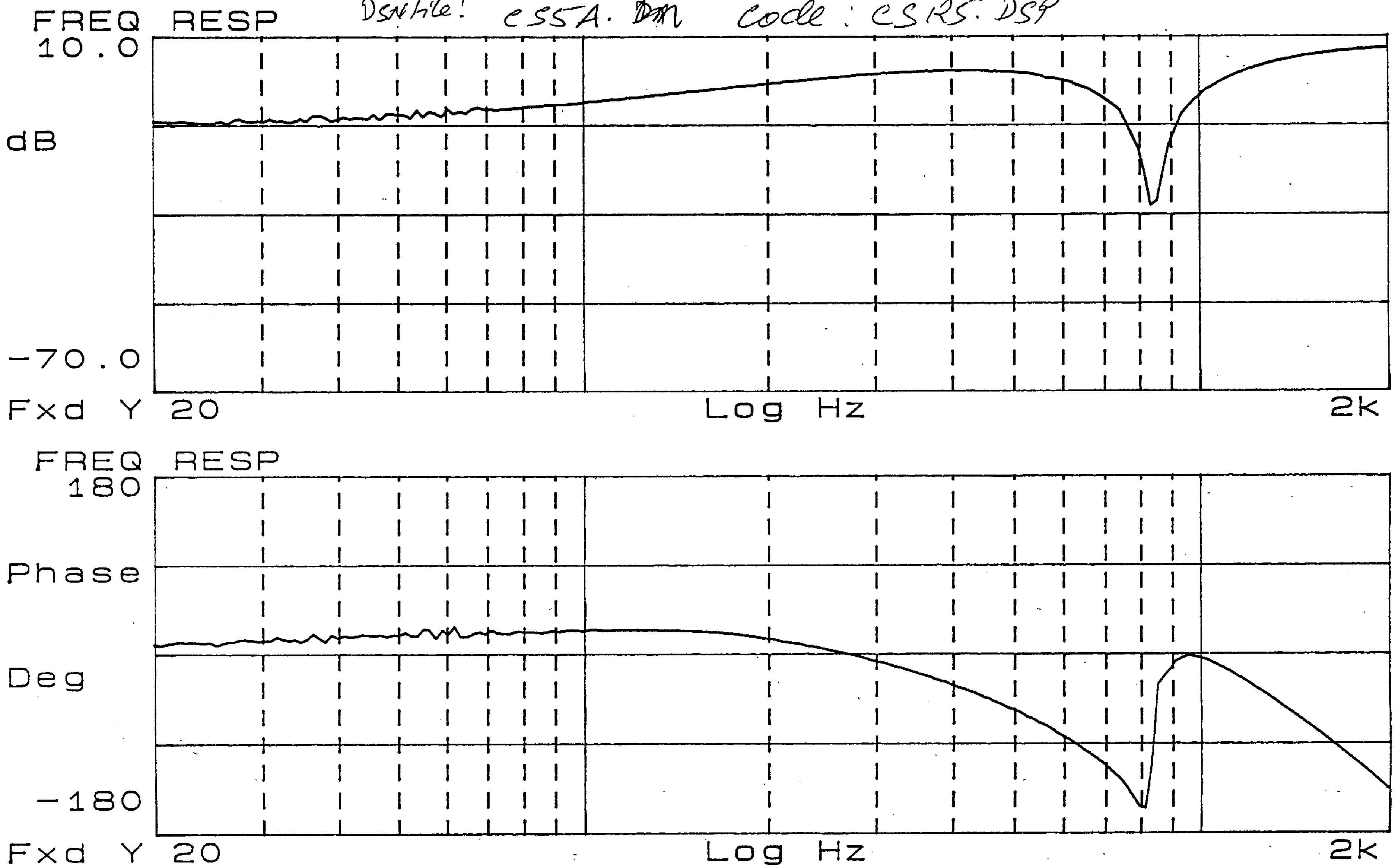


CAL START 10-5

Y1: Comp: XFR FN (B/A)
Sys. Levitated
Source: Swept Sine 100mV pk

B = Curr. Mon.
A = ERROR
Sig. at Y1 Bias
INTEG: ON
Dsn File! CSSA.DM Code: CSRS.DSP

5/24/98

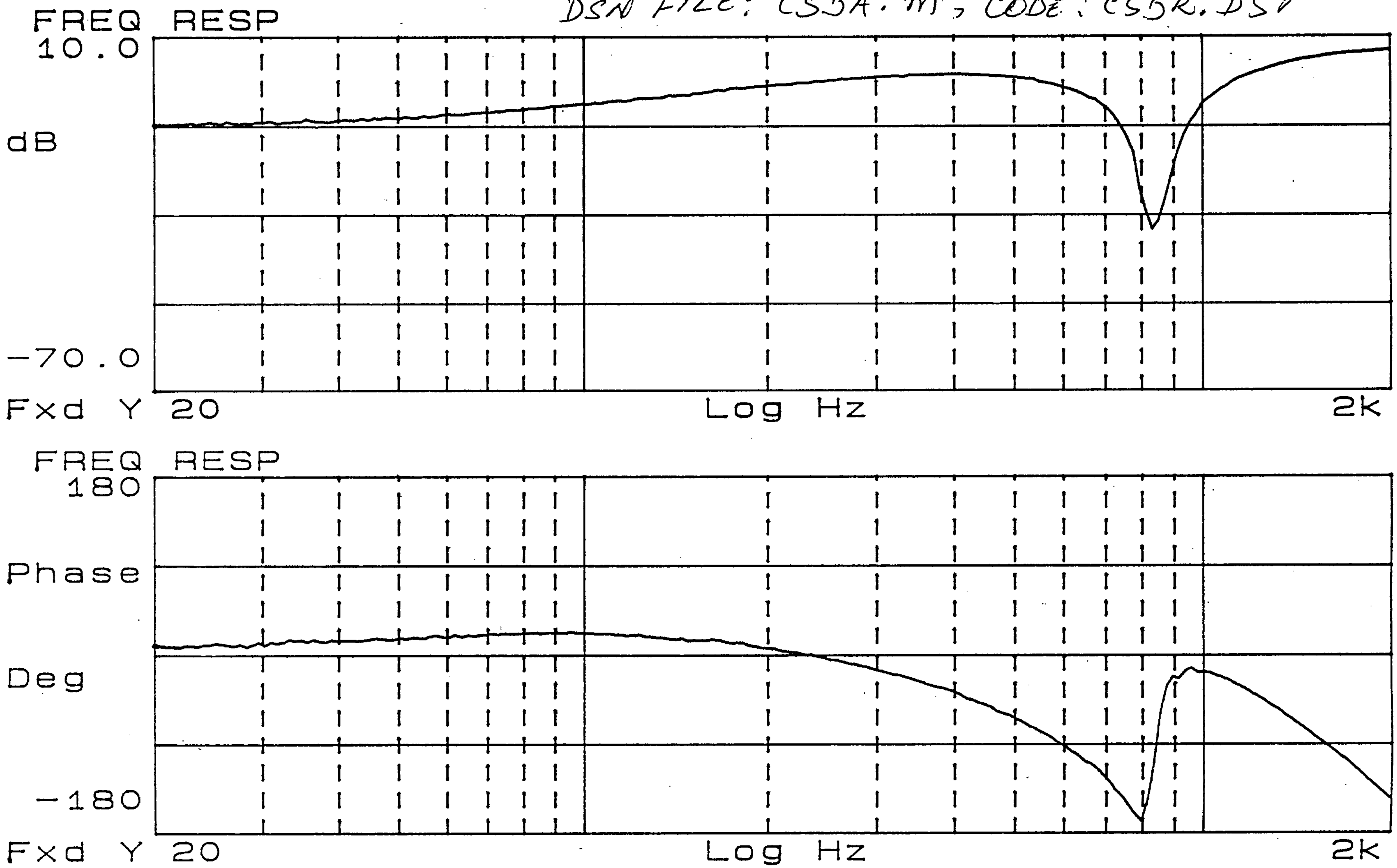


CAL START

ID-6

X2. Comp: XPR FN (B/A) B = Curr. Mon. X2 3/24/98

Source: Swept Sine A = ERR. X2
100 mV PK Sig @ X2 Bias
INTEG ON
DSN FILE: CS5A.m, CODE: CS5R.DSP



CAL START

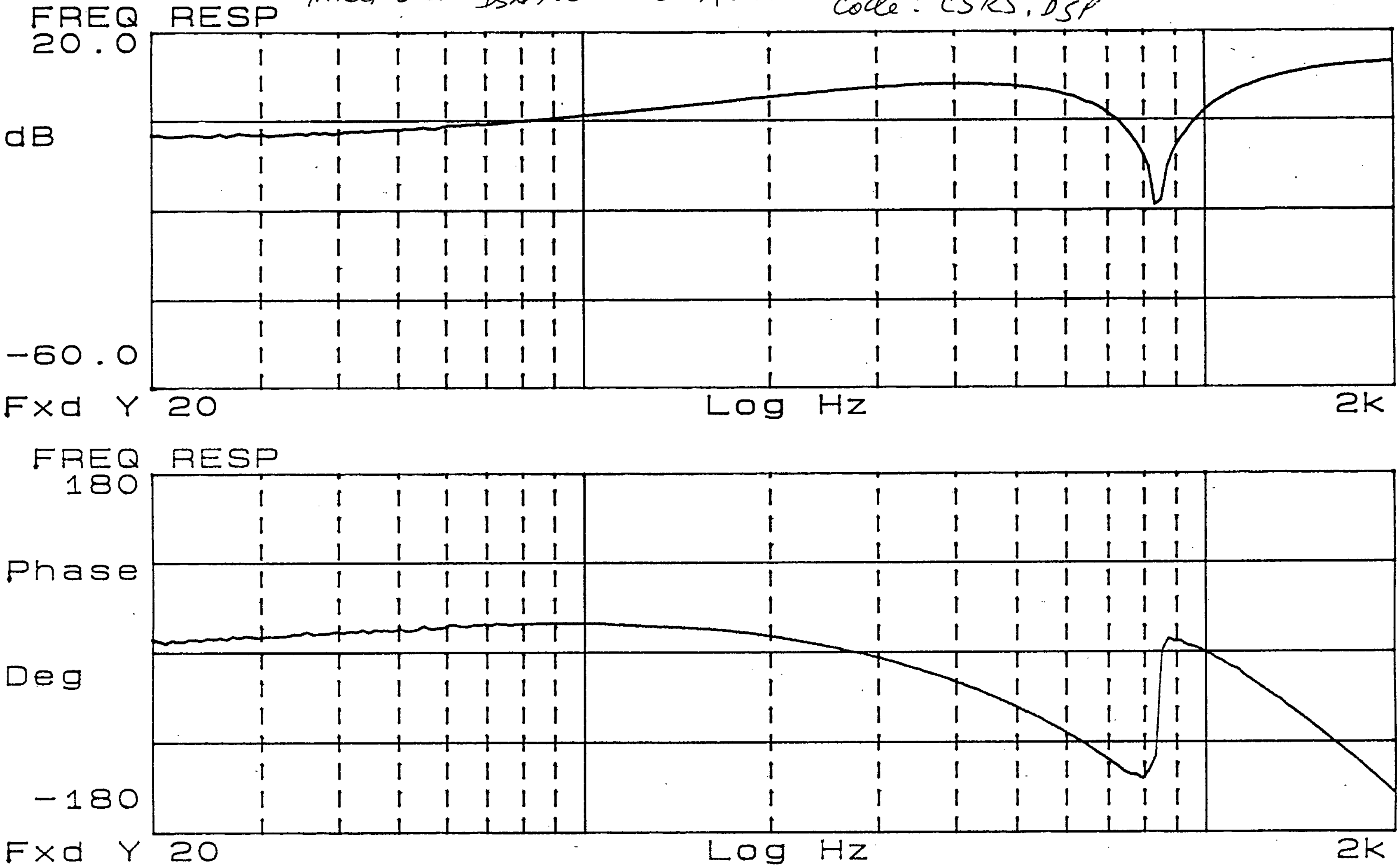
1D-7

Y2: Comp. XFR FN (B/A) 3/24/98

B = Curr. Mon Y2
A = ERROR Y2
Sig. @ Y2 Bias

Source: Swept Sine
100 mV

INTEG ON. DSN FILE: CS5A.m Code: CSR5.DSP

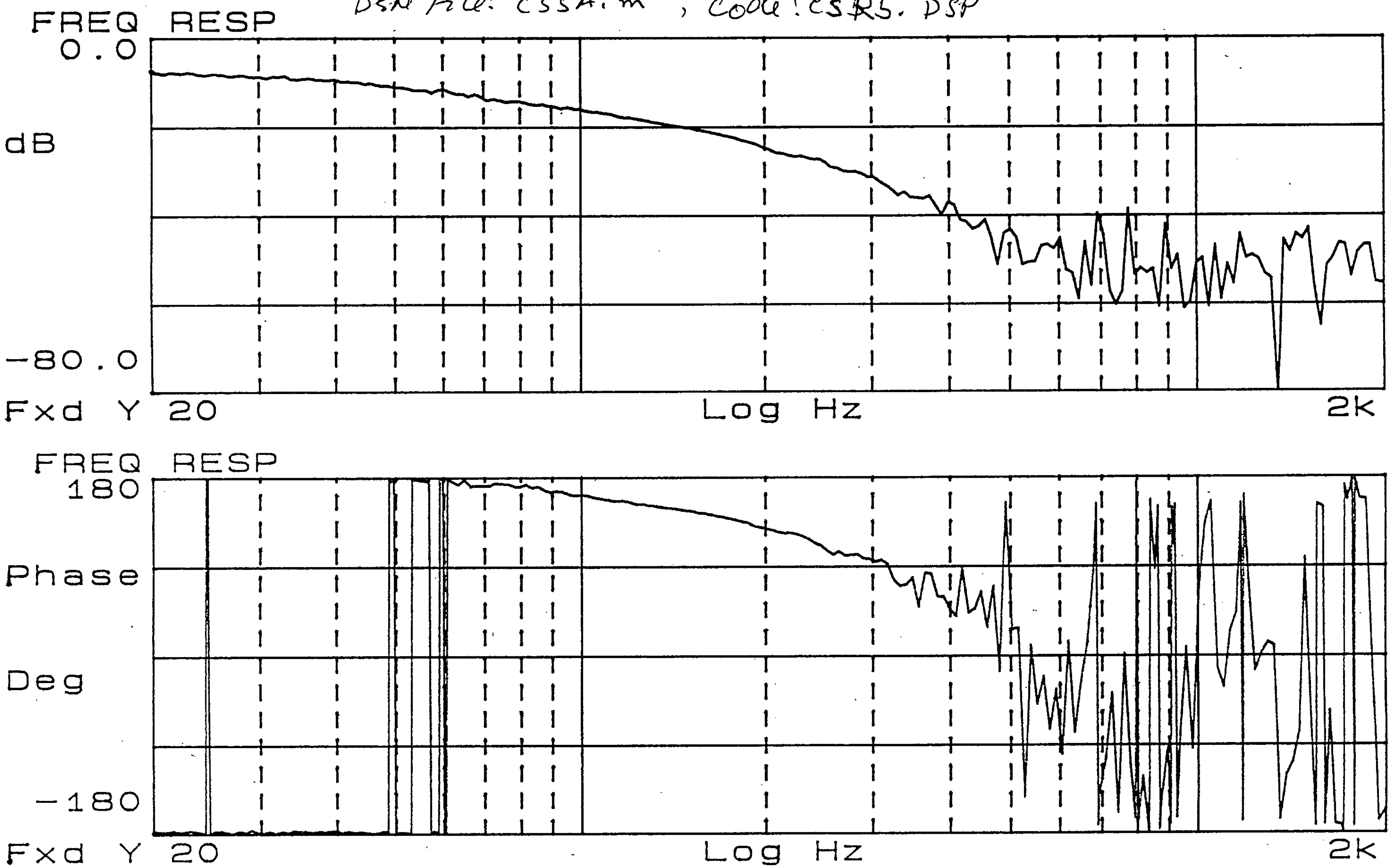


1D-8

X1: XFR FN (B/A) B = Pos X1
A = Cur. X1
Sig. @ Bias X1

Sig. Source: Swept Sine 100mV pk

Dsn File: CS5A.m , Code: CSR5.DSP



CAC START

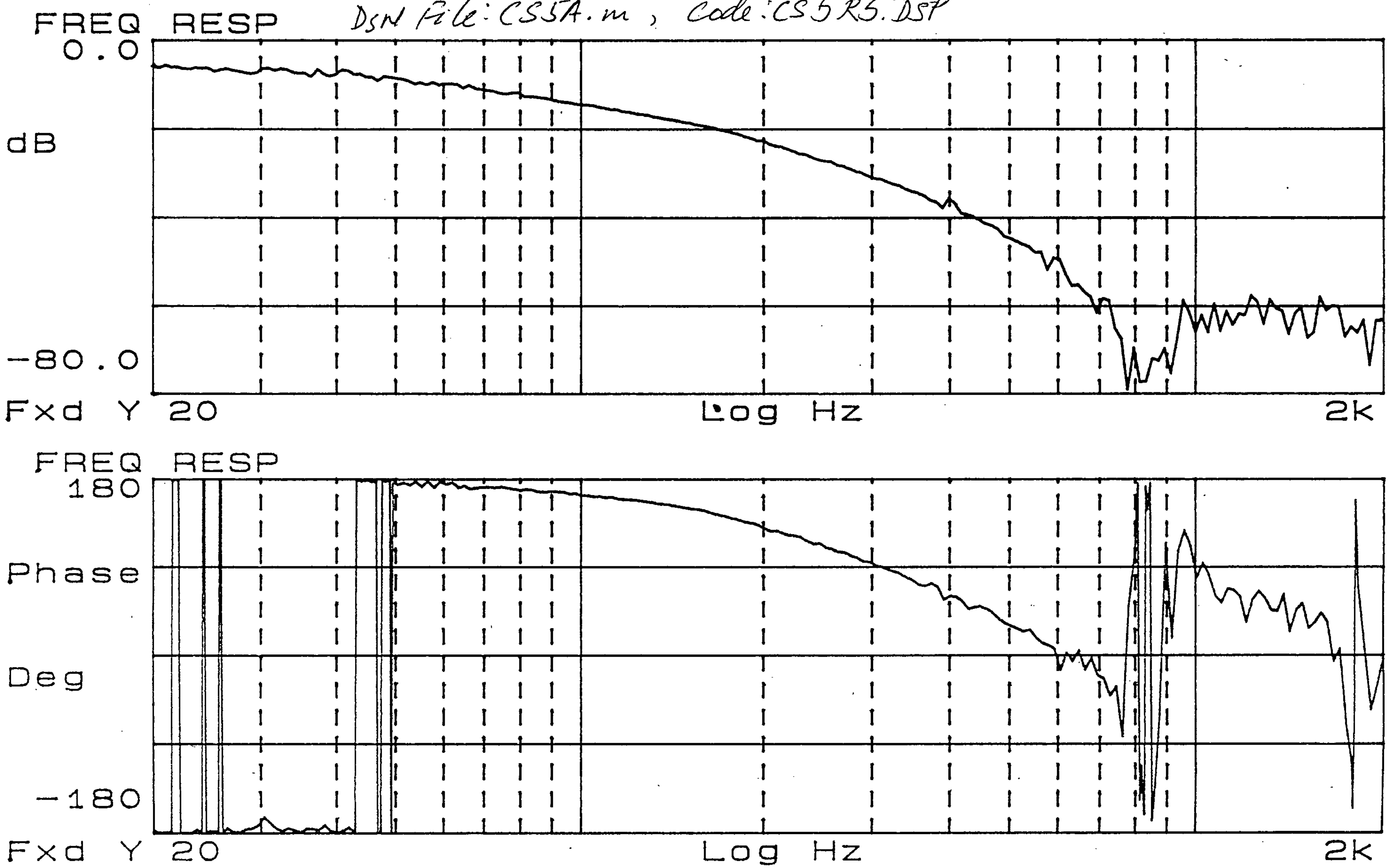
10-9

Y! XFR FN (CSA): B = POS Y1
A = CUR. Y1
Sig. @ Bias X1

3/24/98

Source: Swept Sine / 100mV Pk

DSN File: CS5A.m, Code: CS5R5.DSP



CAL START

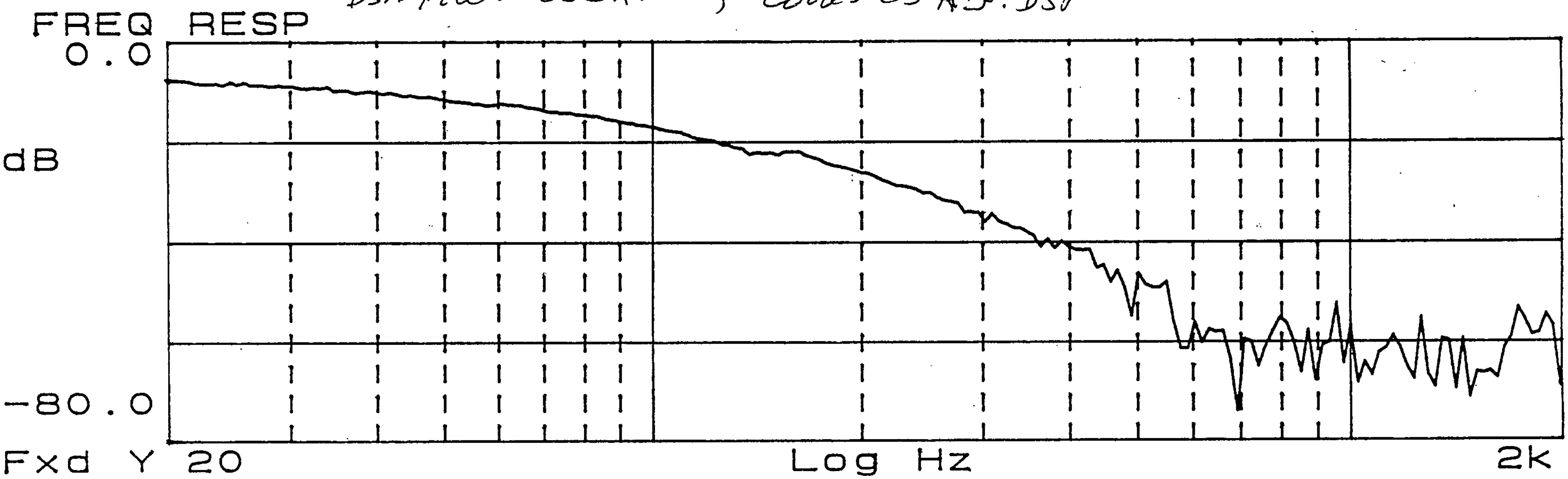
1D-10

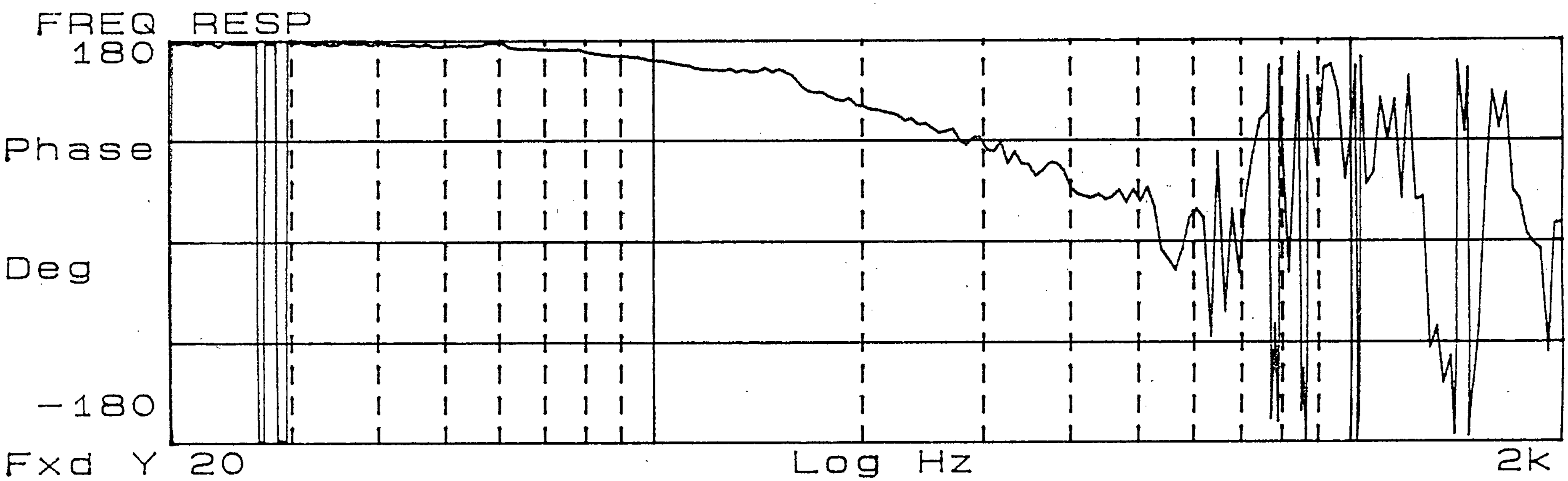
X2: ~~Closed~~ Loop XFR FN(B/A) . B = Pos. X2
A = ERR X2
Sig. @ Bias X2

Source: 100 mV Swept Sine

[illegible]

DSN file: CS5A.m, code = CS[illegible].DSP



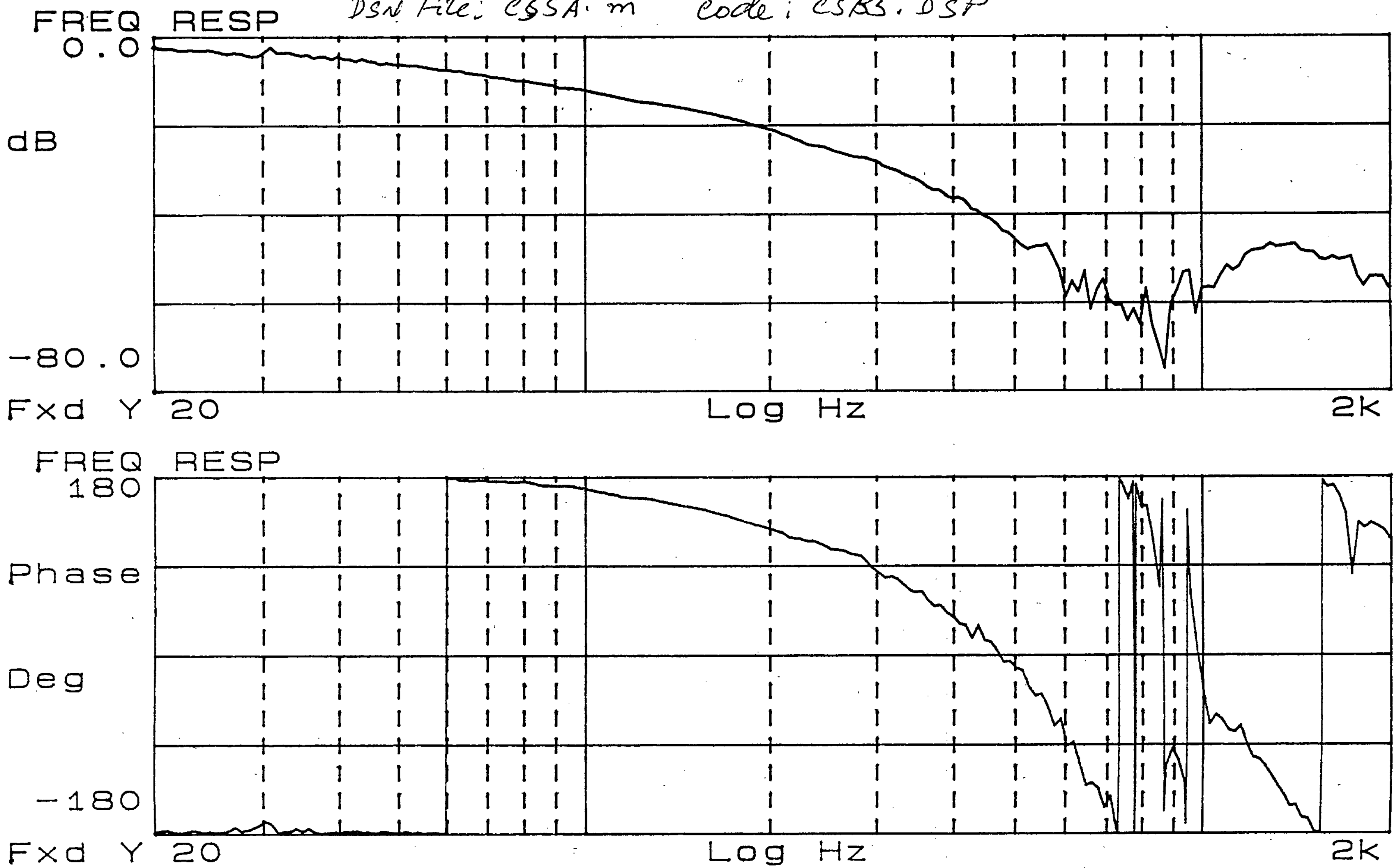


CAL START

ID-11

I. ~~Closed~~ Loop XFR FN (B/A) ; B = Position Y2
A = ERROR Y2
Signal Level: 100 mV Swept Sine
sig. @ Bias Y2

DSN File: CSSA.m   code: CSB5.DSP



Carl Stabb

10-12

Y1: ~~[illegible]~~ Xfr fn (cmd).

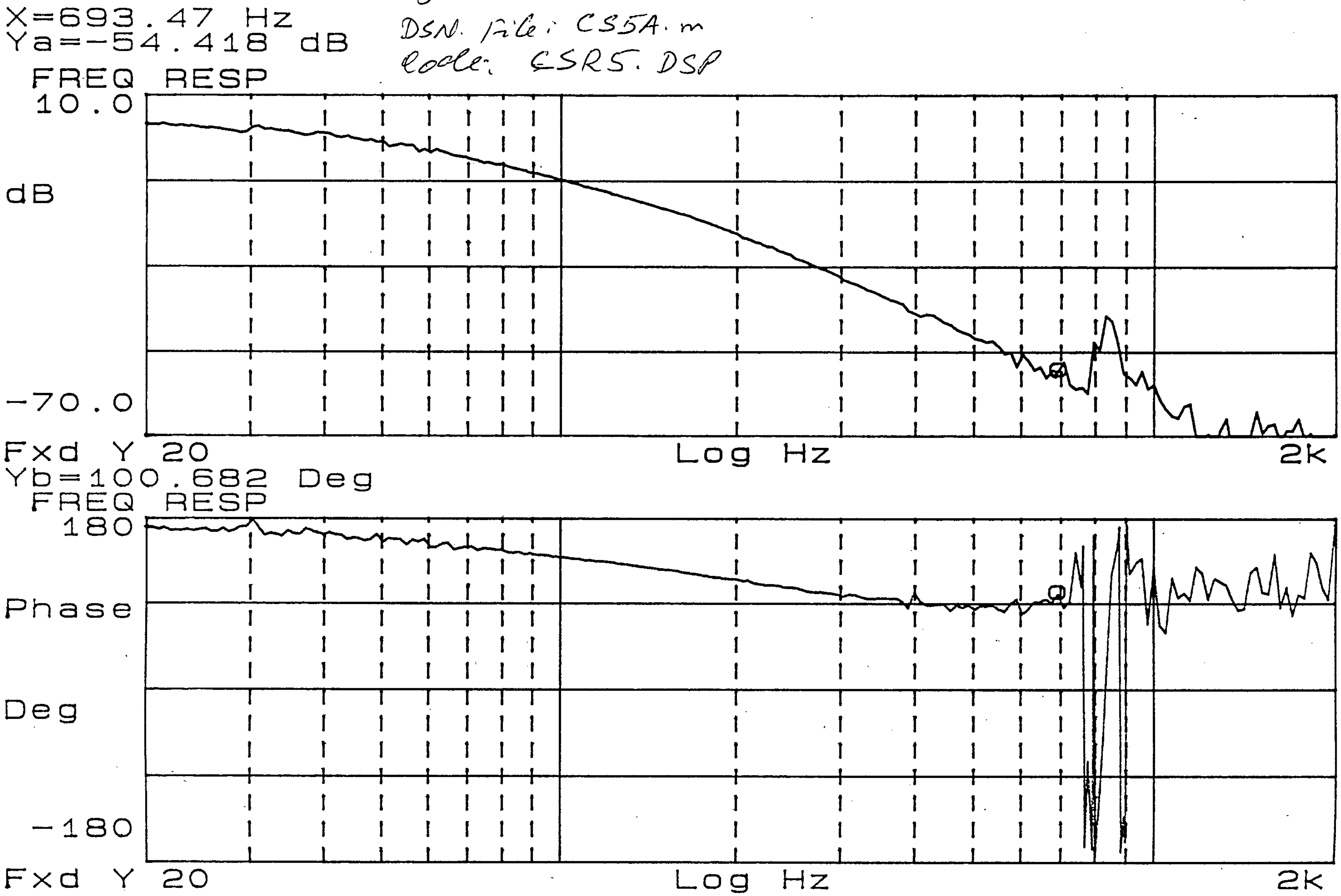
A = Cur. Y1

Sig @ Bias Y1 Source: Swept Sine 100 mV pk

3/24/98

DSN. File: CS5A.m

Code: CSR5.DSP



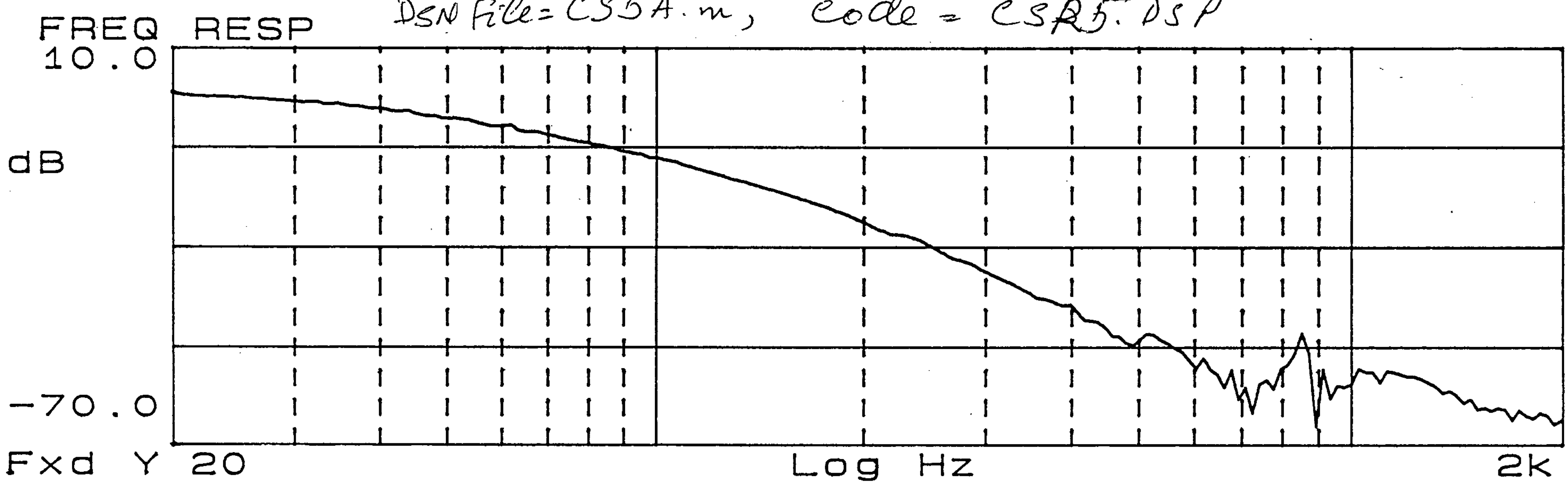
CA2 START

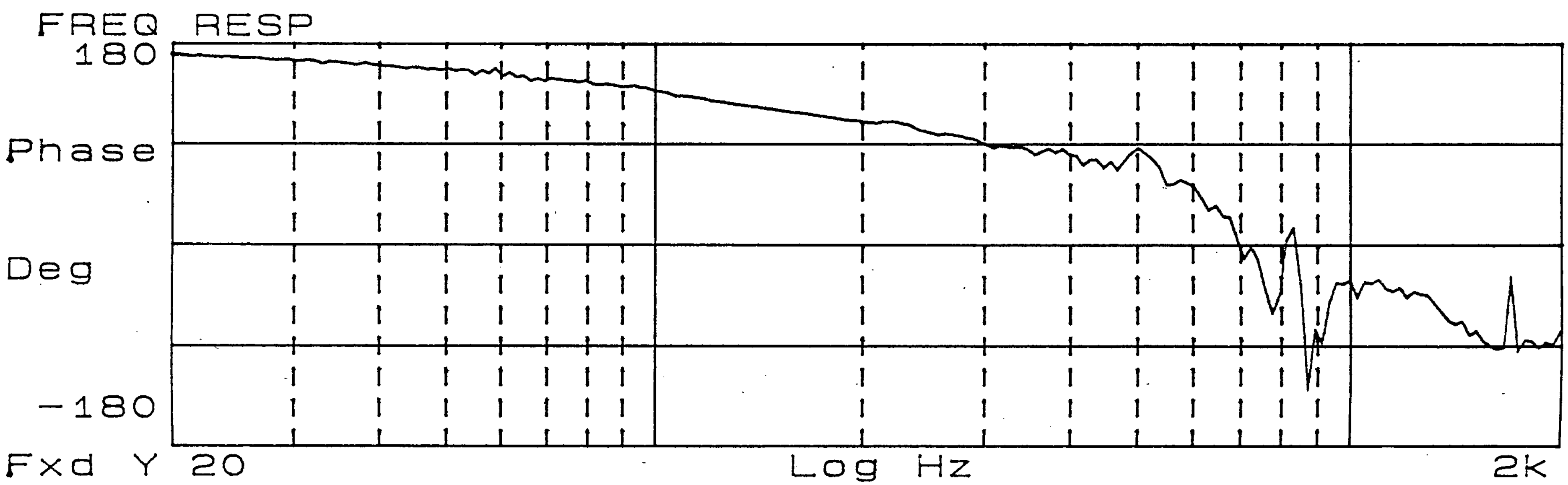
D-13

X1: XFR FN (B/A): B = Pos. X1
A = Curr. X1
Source: 100mVpk Swept Sine Sig. @ Bias X1

3/24/98

DSN File = CS5A.m, code = CSR5.DSP



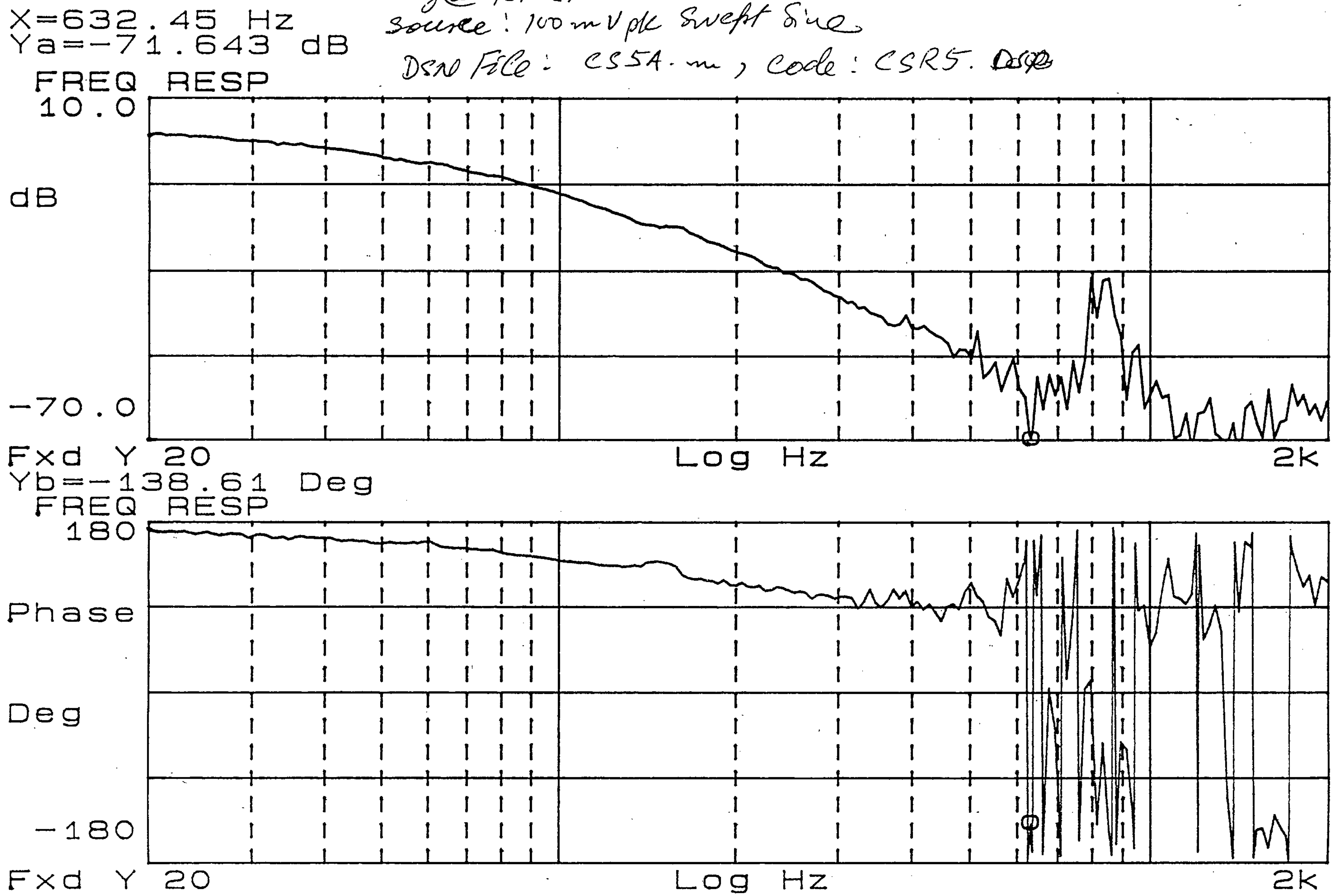


CM START

ID-14

X2: XFR FN (B/A)　　B = Pos. X2
A = Curr. X2
Sig @ Bias X2
Source: 100 mV pk Swept Sine
DSN File: CS5A.m, Code: CSR5.DSP

3/24/98

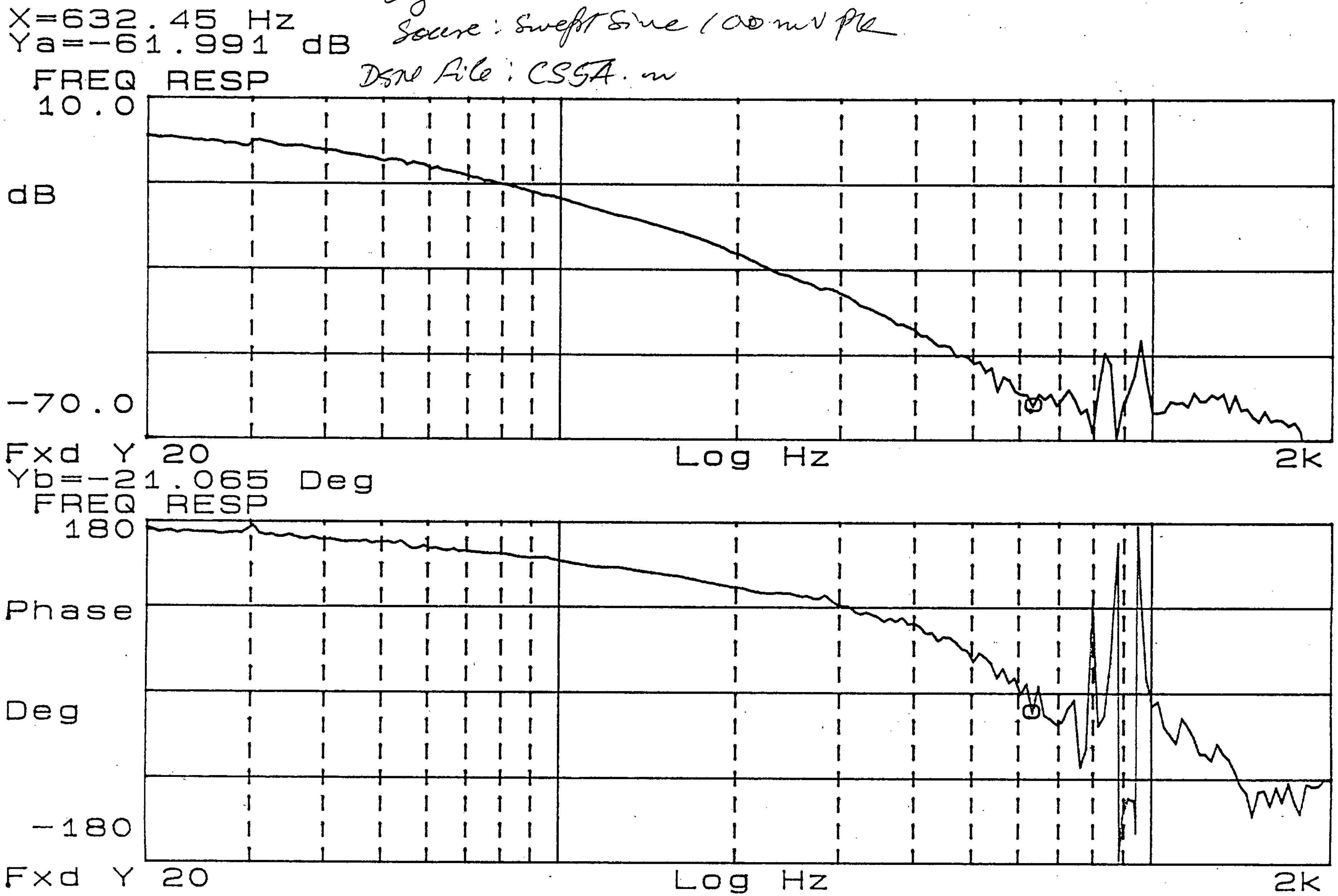


Cal Start

1D-15

YZ. [illegible] XHL 7YY (16 A) B = Pos YZ
A = CER. YZ
Sig. @ Bias YZ
Source: Swept Sine 100 mV Pk
Dsn File: CSSA.m

3/24/98

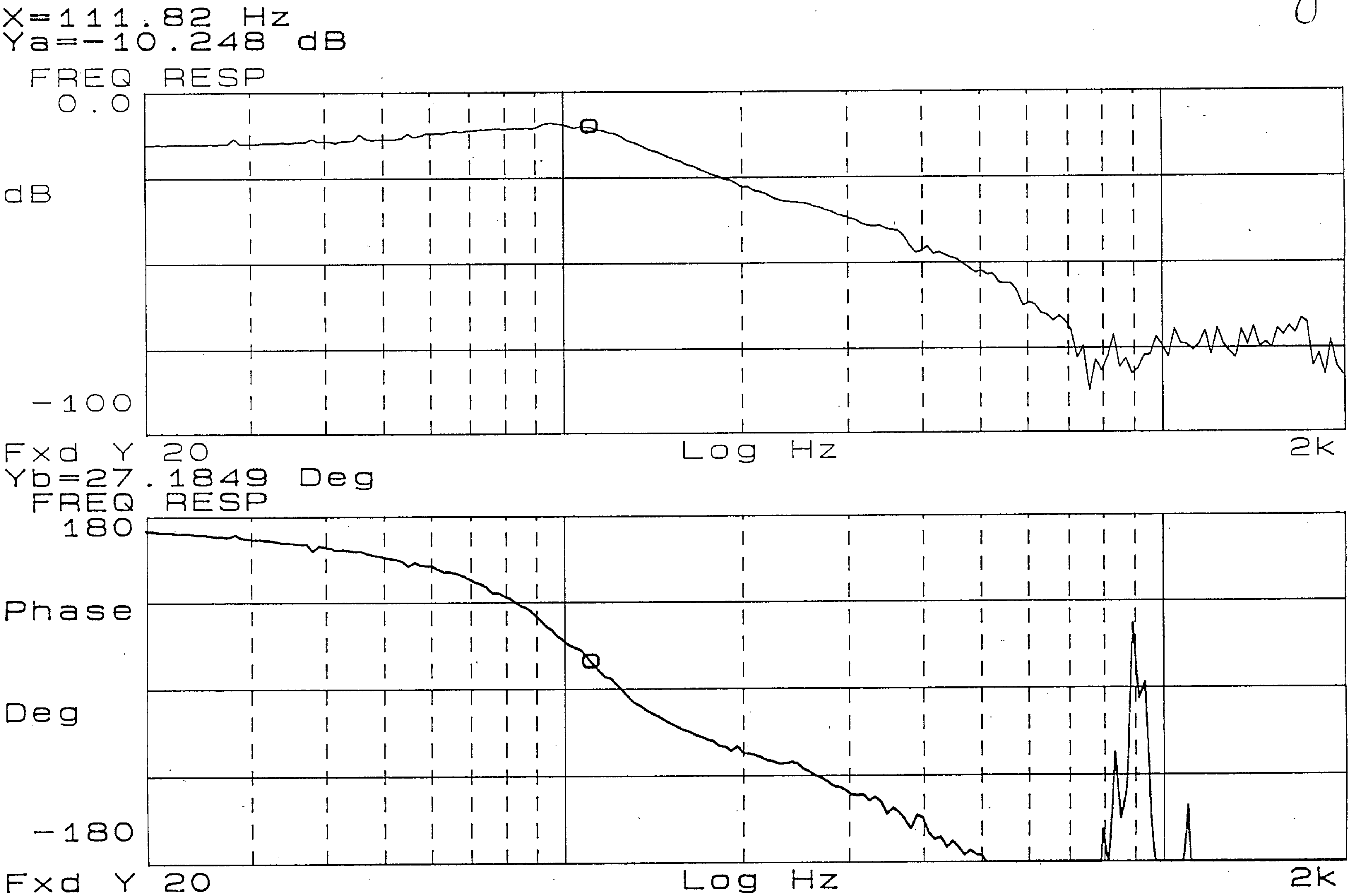


[illegible]

1D-16

X1; Pos/Bias Closed Loop XFR Fct 4/3/98

M. Z

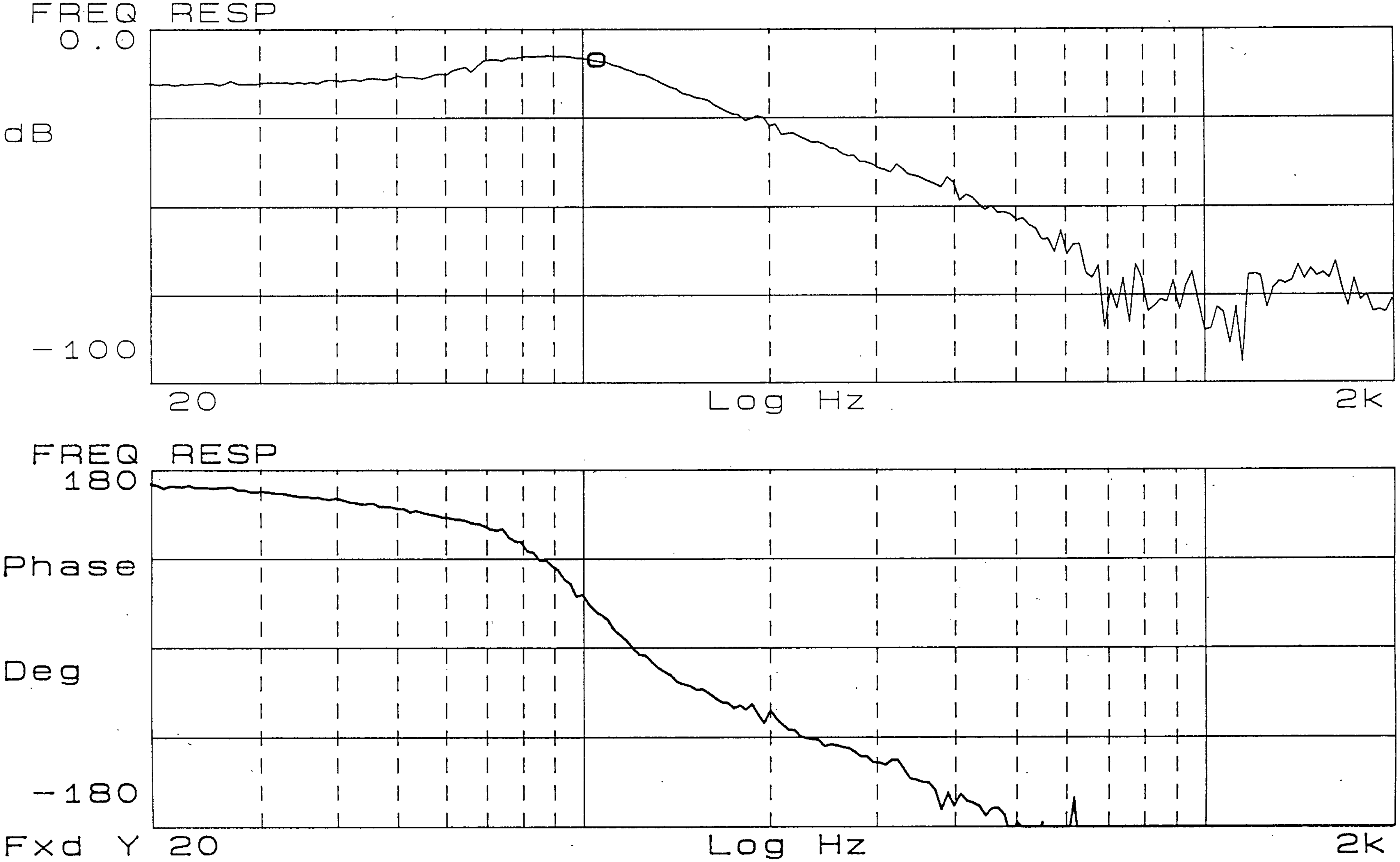


1D-17

T. r…/BIAS Closed Loop 4/3/98

S.S. 80 mV

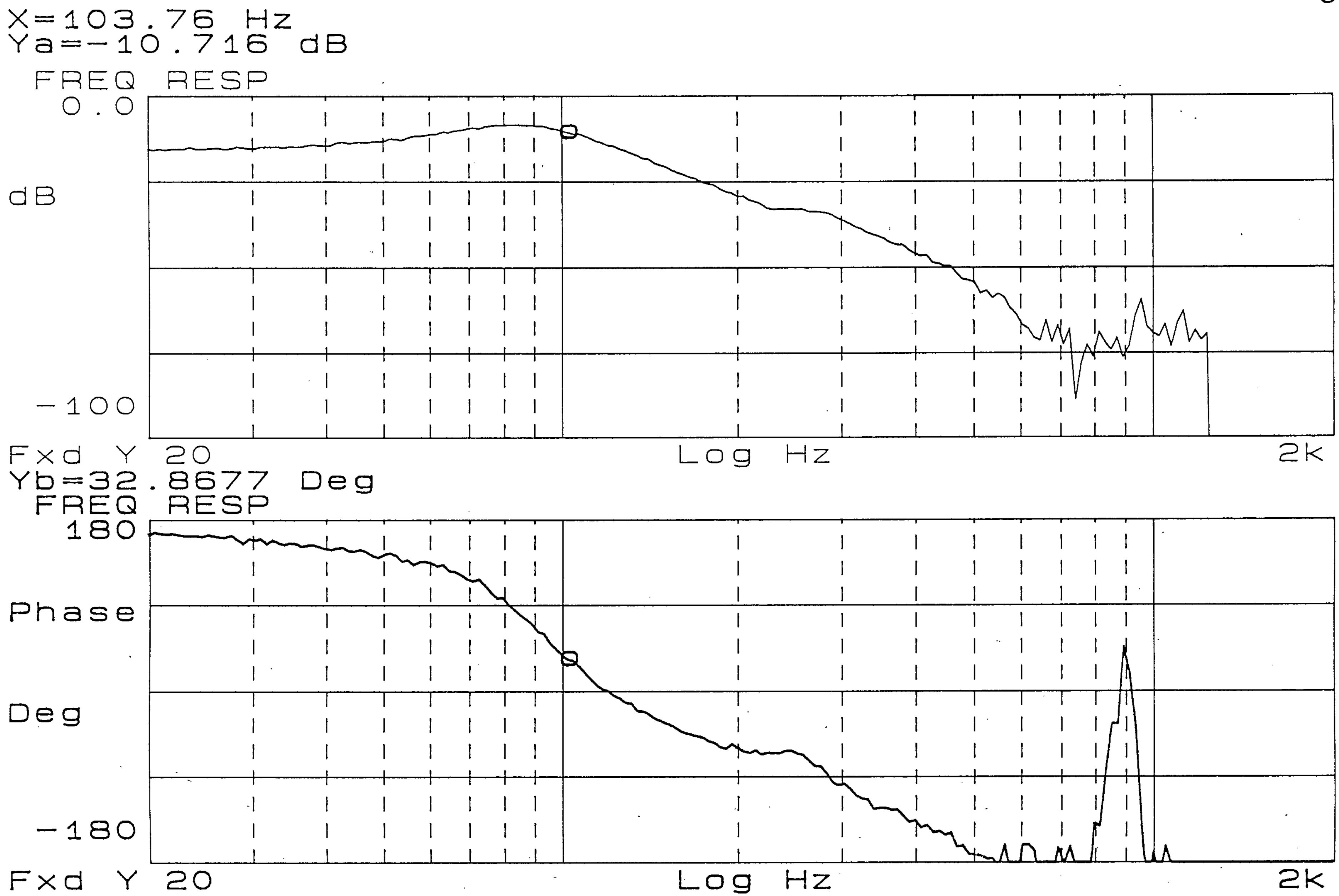
X=106.18 Hz
Ya=-8.7332 dB



1D-18

X_2 Closed Loop

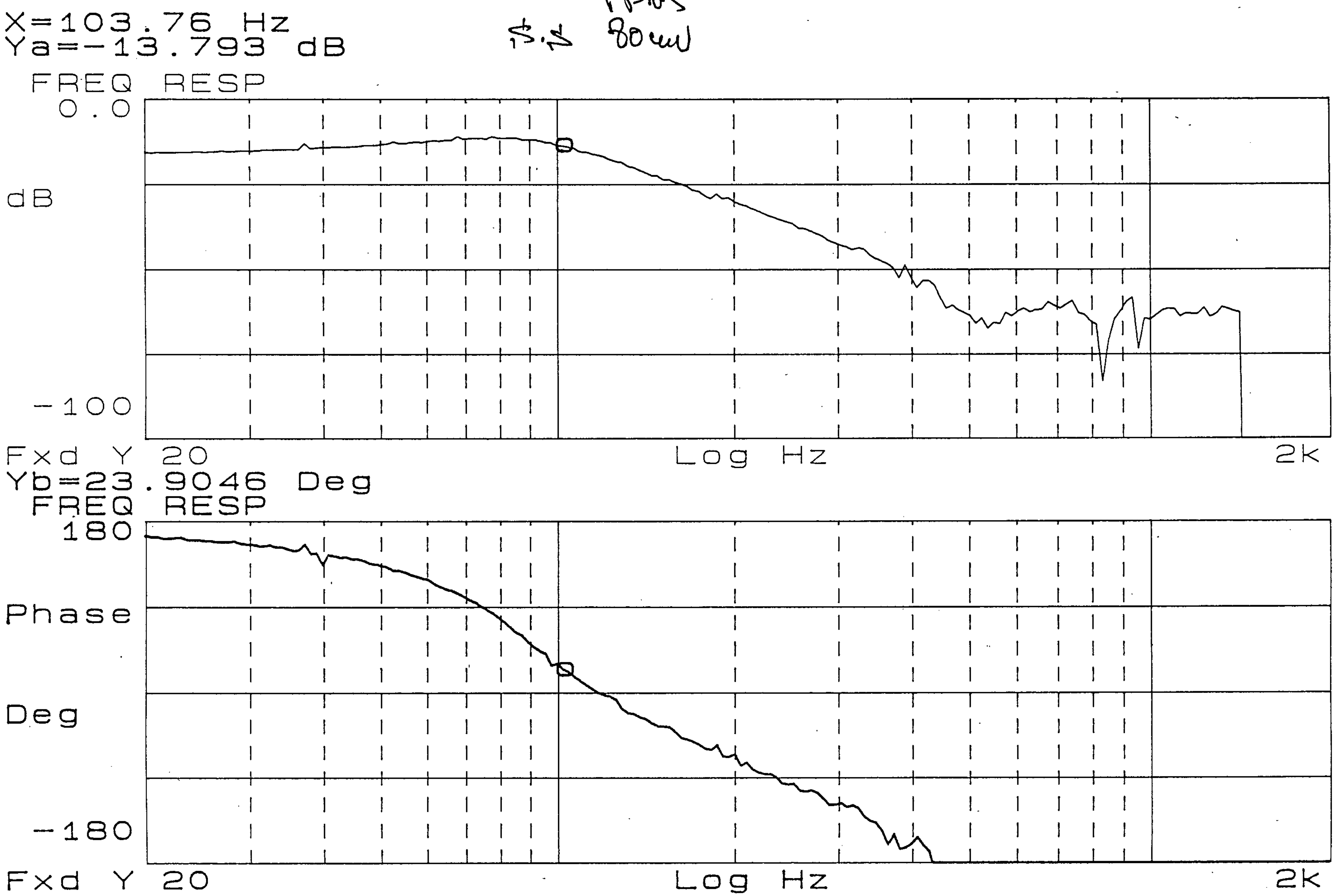
S.S. 80mV



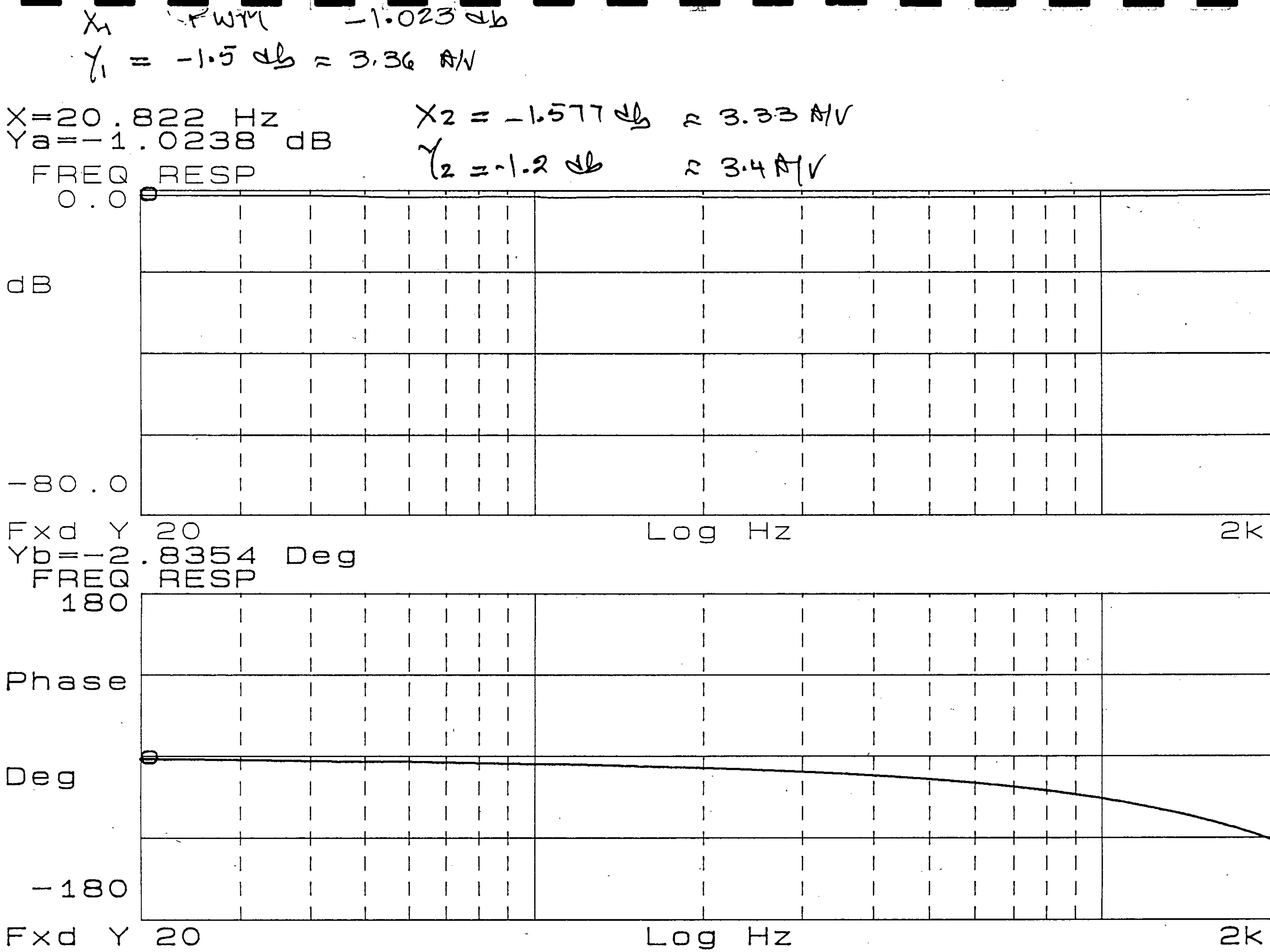
1D-19

Y2 Closed Loop Pos/Bias | Bias S.S 80mV

2:10 P.M. 4/3/98 M.Z



1D-20


X1 FWM −1.023 db
Y1 = −1.5 db ≈ 3.36 A/V
X=20.822 Hz
Ya=−1.0238 dB
X2 = −1.577 db ≈ 3.33 A/V
Y2 = −1.2 db ≈ 3.4 A/V
FREQ RESP
0.0
dB
−80.0
Fxd Y 20
Log Hz
2k
Yb=−2.8354 Deg
FREQ RESP
180
Phase
Deg
−180
Fxd Y 20
Log Hz
2k

10-21

APPENDIX 2

CALSTART: TEST DATA SHEET

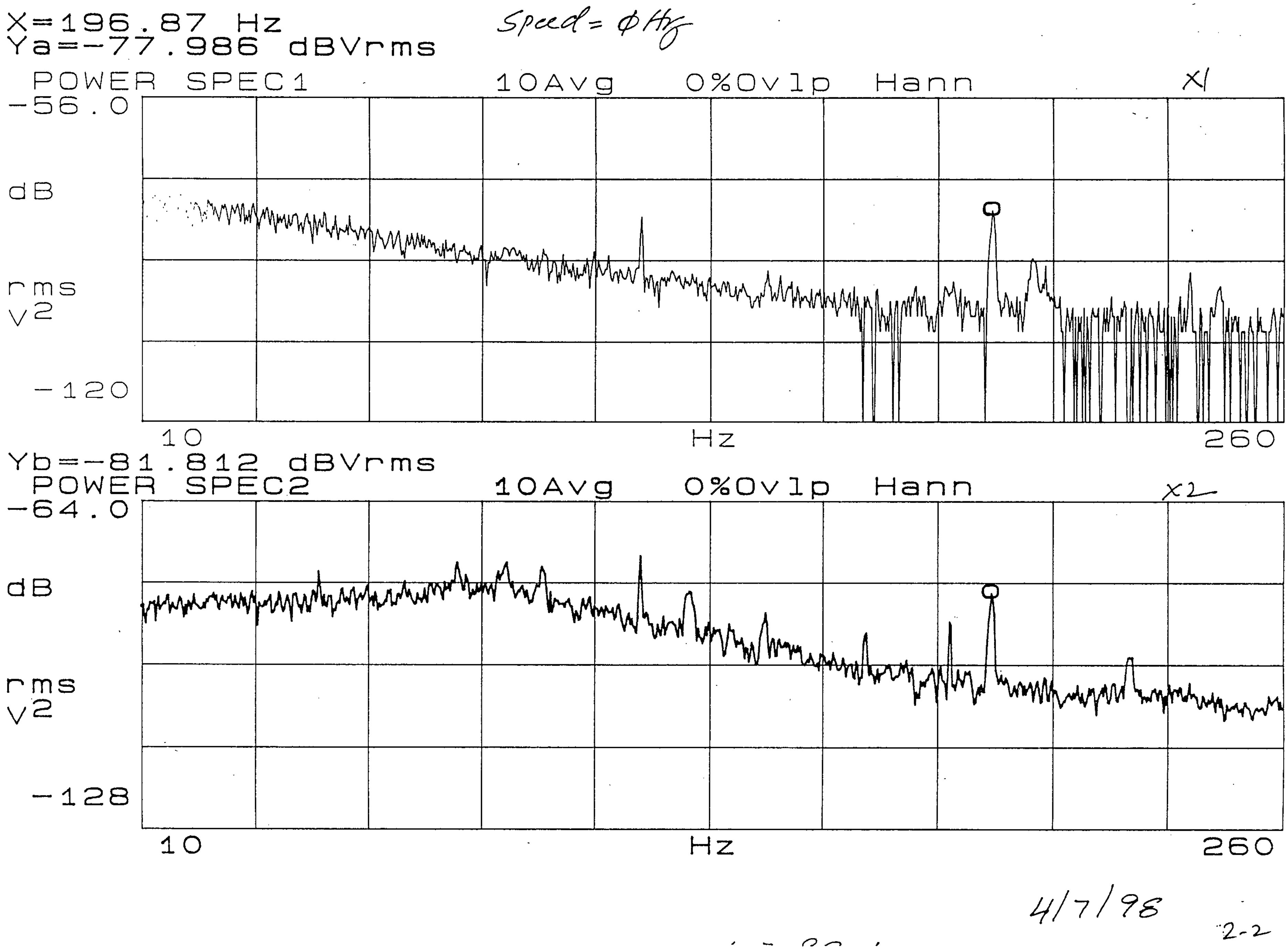
DATE: 4/7/1998

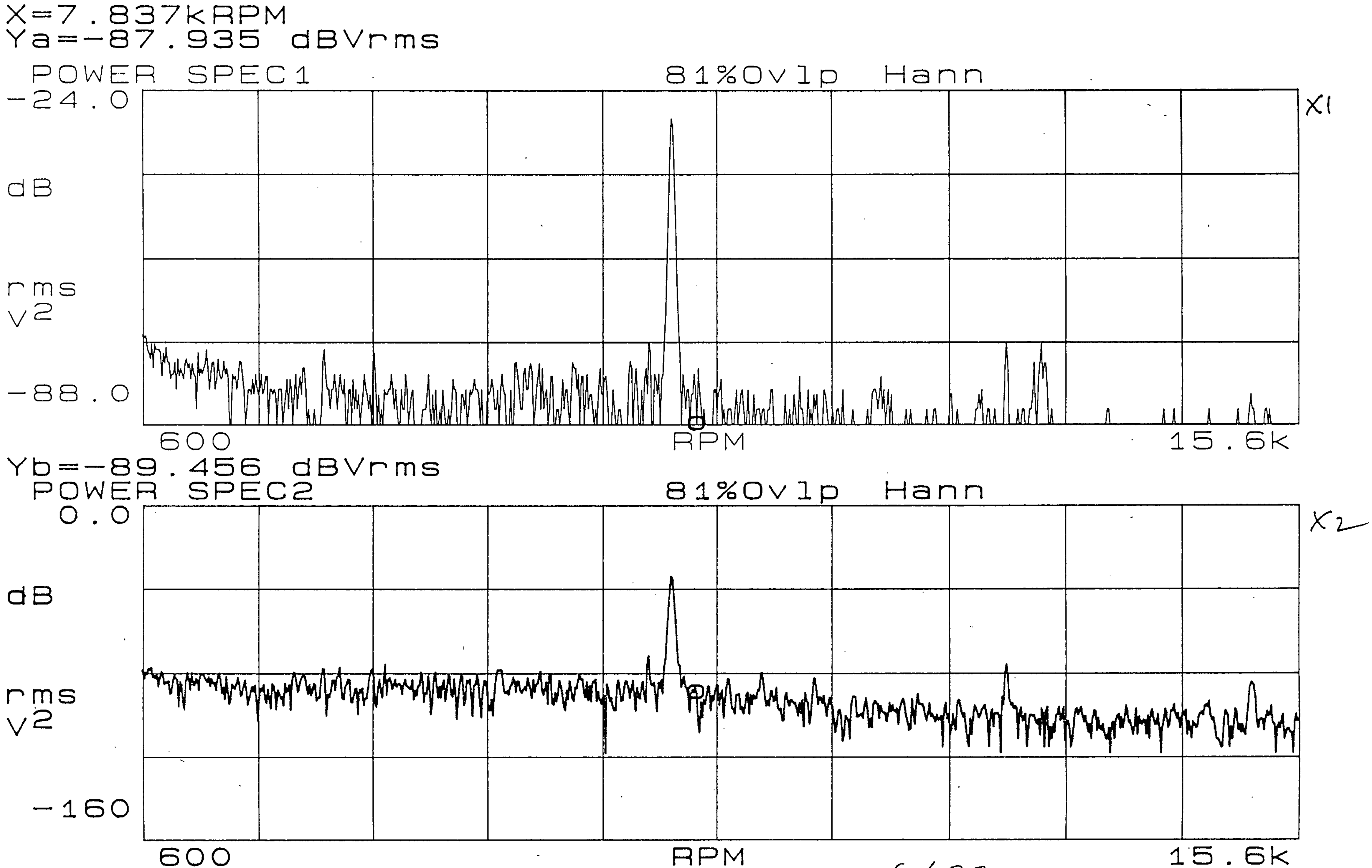
ITEM#	SPEED	TIME	CURRENT MONITOR MEASUREMENTS							
			X1		Y1		X2		Y2	
	Hz		Vdc	Vac	Vdc	Vac	Vdc	Vac	Vdc	Vac
1	Ø	10:30	.372	0.006	-0.075	0.007	0.109	.008	.372	.008
2	130	10:20:40	.353	.195	-.07	0.188	.085	.120	.385	0.095
3	105	10:21:40	.351	.149	-.072	.130	.084	.099	.351	0.073
4	85	10:22:53	.350	.074	-.070	.079	.085	.045	.355	0.045
5	70	10:24:01	.350	.046	-.070	.055	.086	.032	.357	0.032
6	60	10:24:51	.351	.027	-.069	.031	.088	.020	.359	0.021
7	50	10:25:50	.351	.020	-.068	.022	.091	.016	.361	0.017
8	40	10:26:50	.352	.013	-.070	.018	.092	.014	.362	0.015
9	30	10:28:01	.355	.010	-.068	.011	.092	.012	.364	0.014
10	20	10:29:20	.358	.006	-.073	.008	.093	.011	.364	0.012
11	10	10:30:47	.360	.006	-.075	.008	.095	.010	.365	0.011
12	5	10:31:33	.360	.006	-.074	.008	.095	.009	.365	0.010
13	Ø	10:32:30	.362	.005	-.076	.008	.106	.007	.369	.008

MOTOR STATUS: ☑ ENGAGED / ☐ DISENGAGED

DATA TAKEN BY: Asif Khan

Run# 4-7-98-1


X=196.87 Hz
Ya=-77.986 dBVrms
Speed = ϕ Hz
POWER SPEC1
10Avg
0%Ovlp
Hann
X1
-56.0
dB
rms
V2
-120
10
Hz
260
Yb=-81.812 dBVrms
POWER SPEC2
10Avg
0%Ovlp
Hann
X2
-64.0
dB
rms
V2
-128
10
Hz
260
4/7/98
2-2

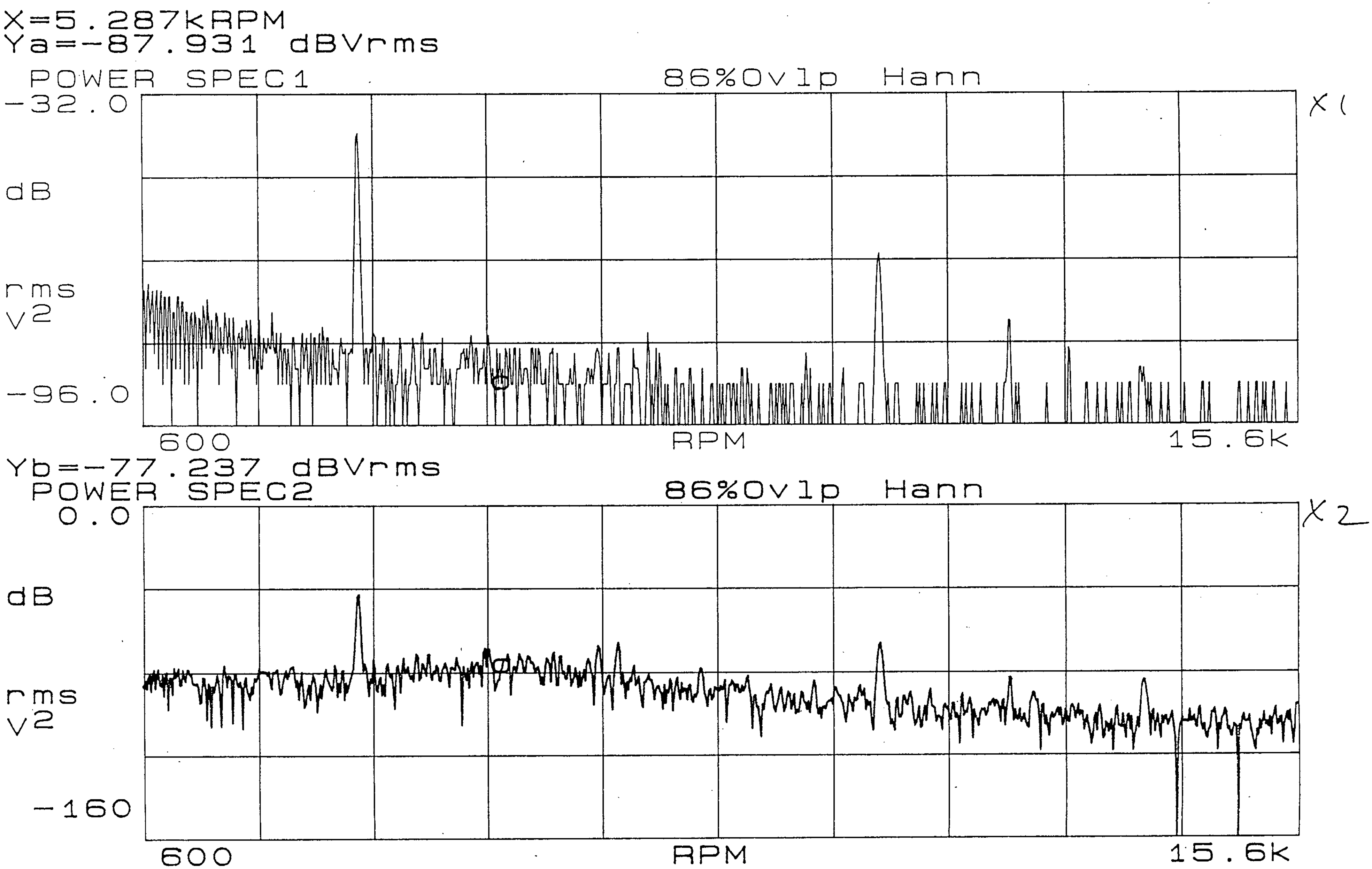


4/7/98

Run# 4-7-98-1

2-3

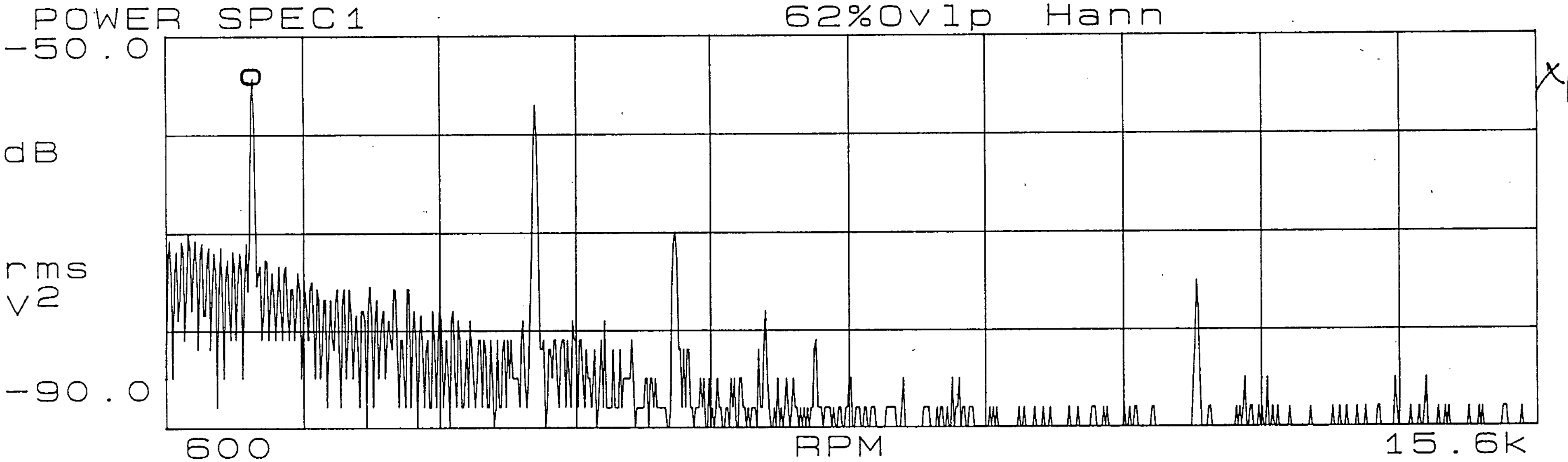
4/7/98



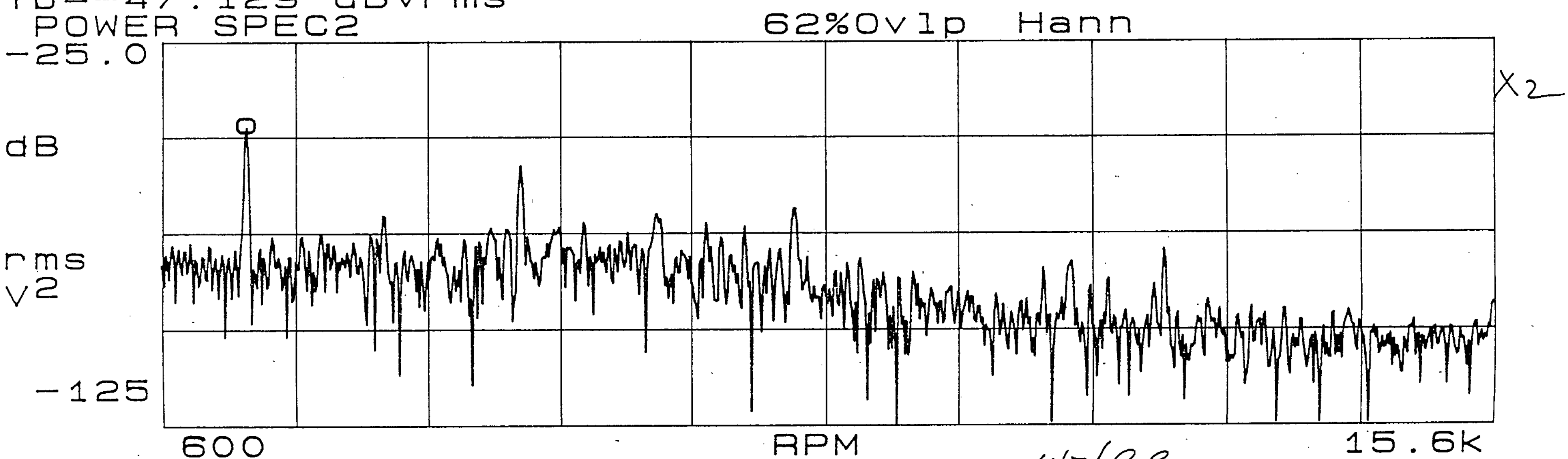
Run# 4-7-98-1

2-4

X=1.556kRPM
Ya=-54.17 dBVrms



Yb=-47.129 dBVrms



4/7/98

Run# 4-7-98-1

2-5

CALSTART: TEST DATA SHEET

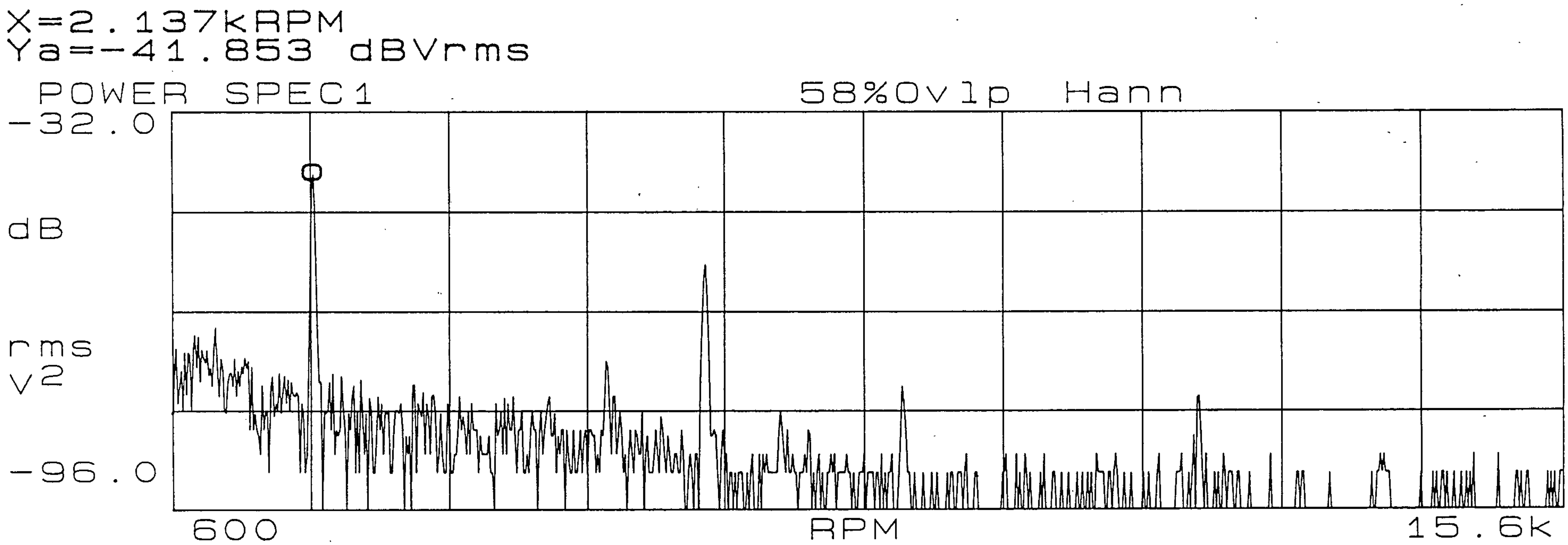
DATE: 4/8

ITEM#	SPEED	TIME	CURRENT MONITOR MEASUREMENTS							
			X1		Y1		X2		Y2	
	Hz		Vdc	Vac	Vdc	Vac	Vdc	Vac	Vdc	Vac
	185	9:35:44a	.28	.17	-.[illegible]	.19	.04	.104	.399	.09
	155	9:36:37	.28	.184	-.071	.207	.039	.112	.4	.08
	140	9:37:10	.281	.199	-.07	.218	.04	.124	.4	.088
	120	9:37:59	.282	.19	-.07	.2	.039	.12	.4	.09
	105	9:38:46	.281	—	-.07	—	.039	—	.399	—
	90	9:39:40	.280	.134	-.071	.124	.039	.1	.399	.08
	80	9:40:25	.279	.1	-.065	.05	.038	.074	.4	.078
	70	9:41:12	.278	.068	-.07	.065	.039	.050	.398	.07
	60	9:42:04	.28	.048	-.069	.047	.039	.037	.399	.05
	50	9:43:02	.278	.035	-.069	.033	.038	.029	.399	.039
	40	9:44:05	.278	.025	-.069	.027	.042	.024	.399	.032
	30	9:45:13	.279	.016	-.069	.023	.038	.027	.4	.026
	20	9:46:27	.280	.013	-.069	.013	.041	.018	.4	.022
	STOP	9:49:29								

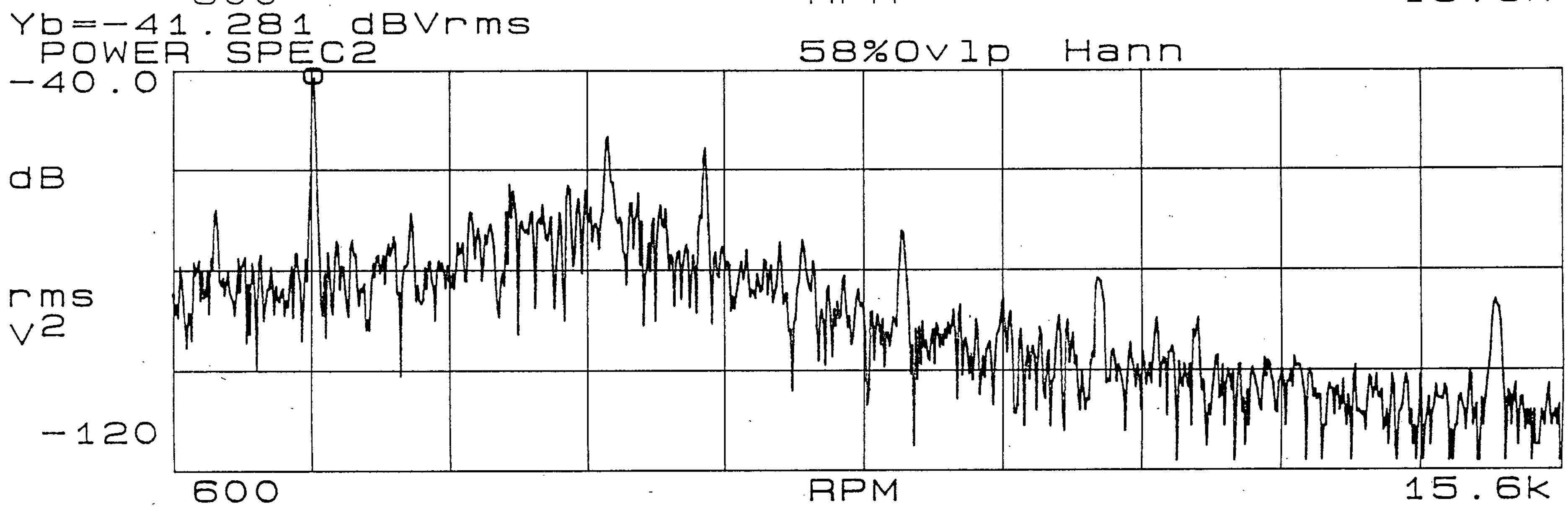
MOTOR STATUS: ☐ ENGAGED / ☐ DISENGAGED

DATA TAKEN BY: MO

RUN# 4-8-98-1

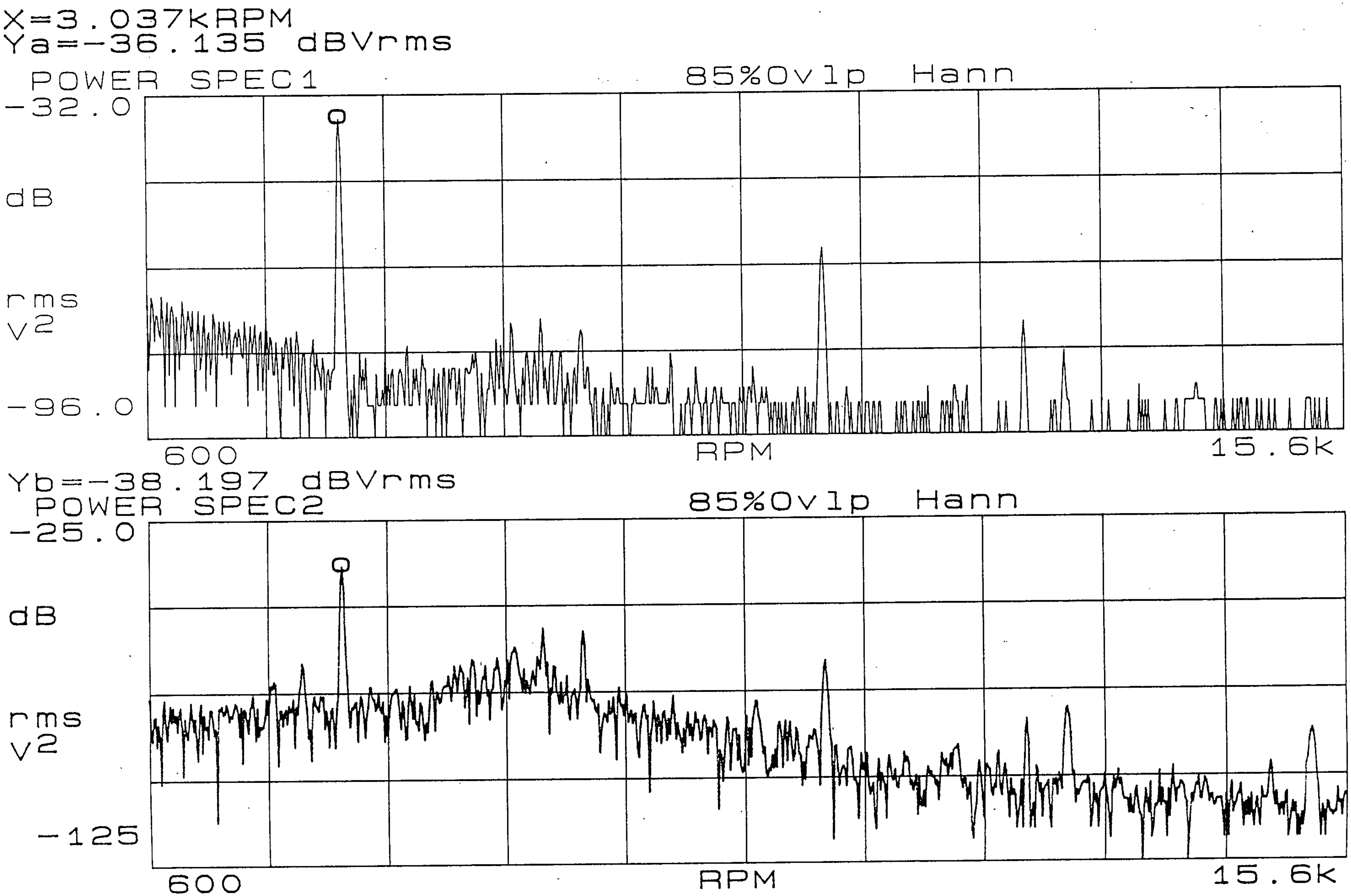


X=2.137kRPM
Ya=-41.853 dBVrms
POWER SPEC1
58%Ovlp Hann
-32.0
dB
rms
V2
-96.0
600
RPM
15.6k



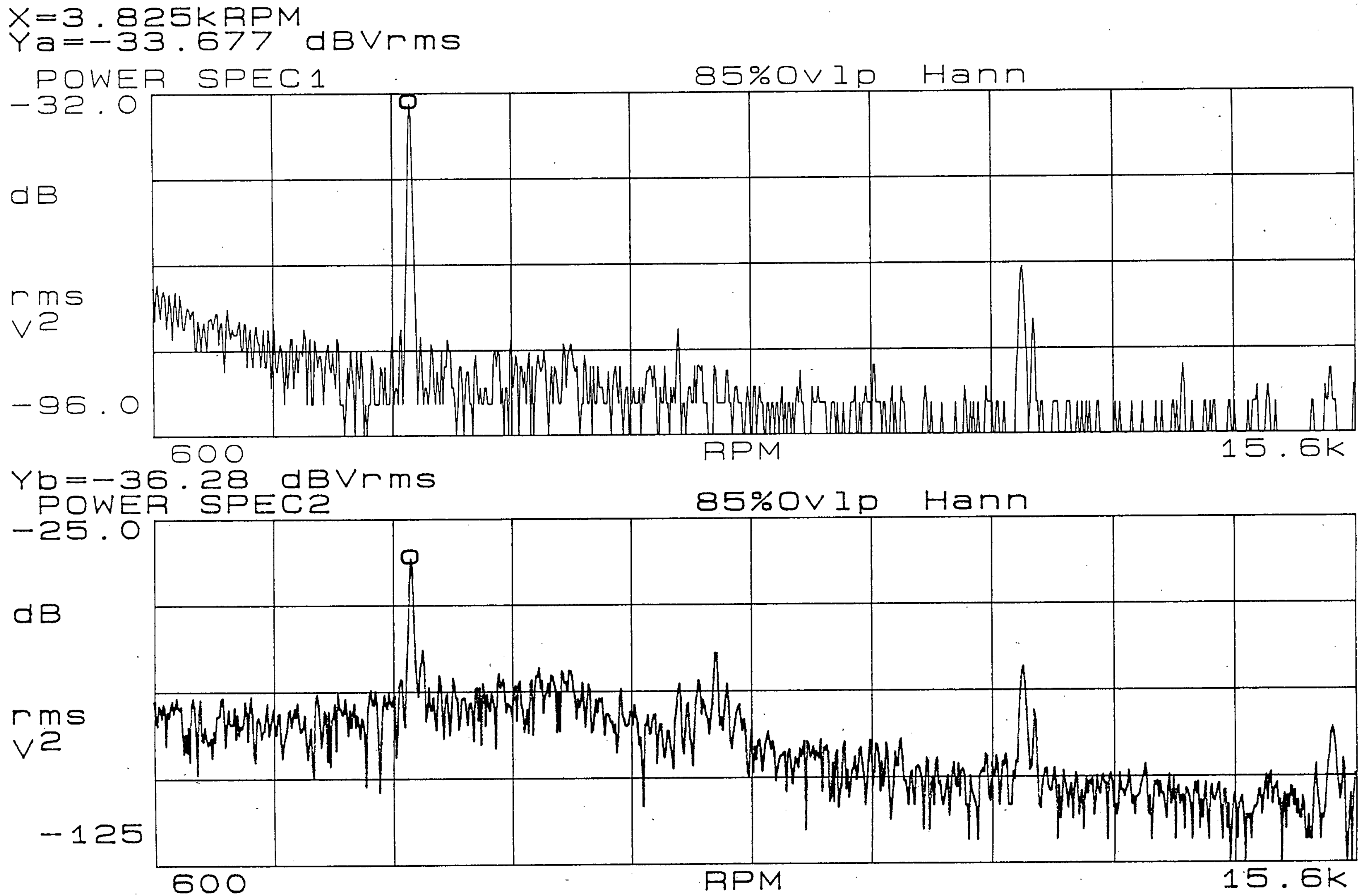
Yb=-41.281 dBVrms
POWER SPEC2
58%Ovlp Hann
-40.0
dB
rms
V2
-120
600
RPM
15.6k

Run# 4-8-98-1



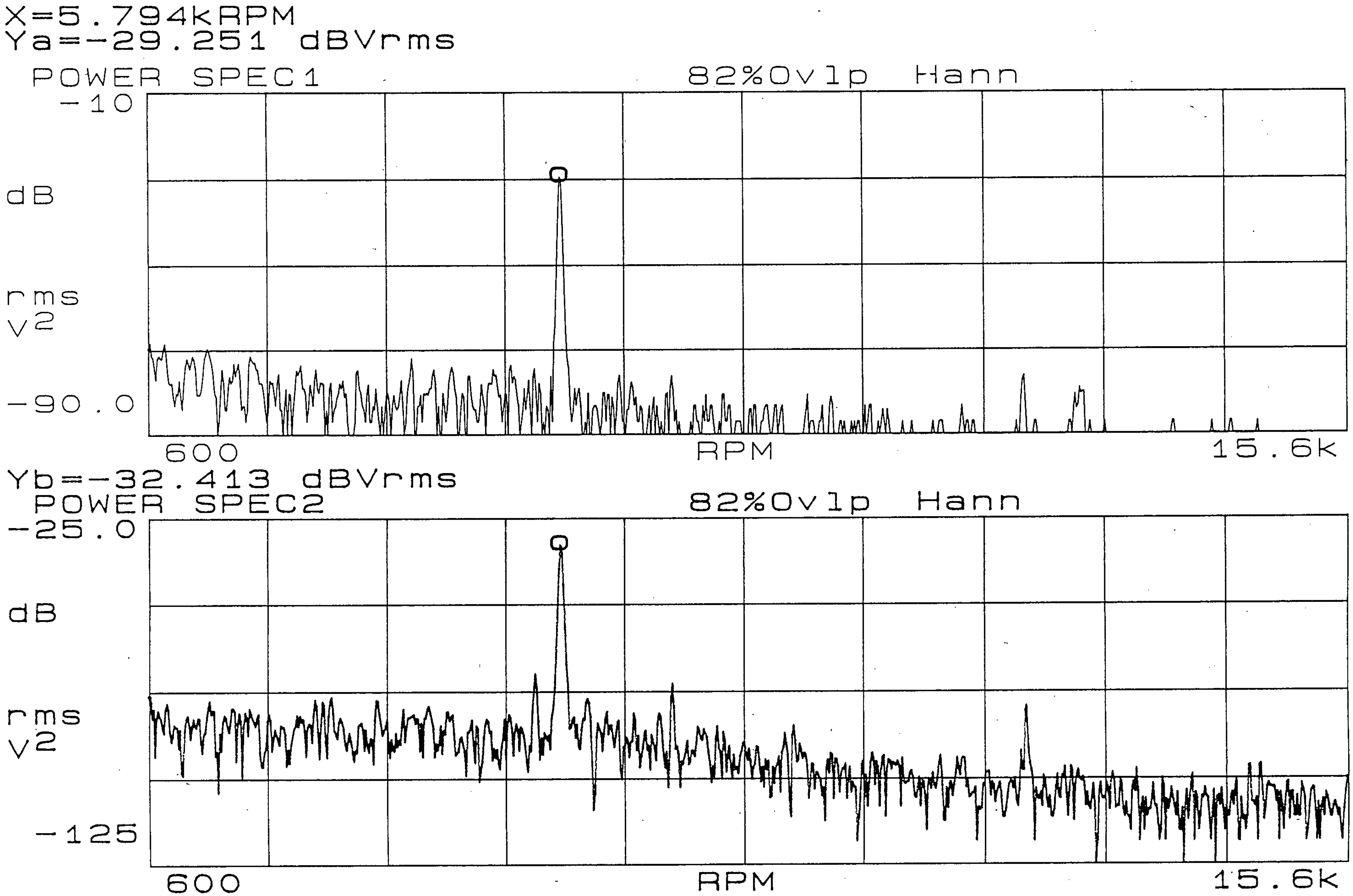
X=3.037kRPM
Ya=-36.135 dBVrms
POWER SPEC1
85%Ovlp Hann
-32.0
dB
rms
V2
-96.0
600
RPM
15.6k
Yb=-38.197 dBVrms
POWER SPEC2
85%Ovlp Hann
-25.0
dB
rms
V2
-125
600
RPM
15.6k

RUN 4-8-98-1


X=3.825kRPM
Ya=-33.677 dBVrms
POWER SPEC1
85%Ovlp Hann
-32.0
dB
rms
V2
-96.0
600
RPM
15.6k
Yb=-36.28 dBVrms
POWER SPEC2
85%Ovlp Hann
-25.0
dB
rms
V2
-125
600
RPM
15.6k

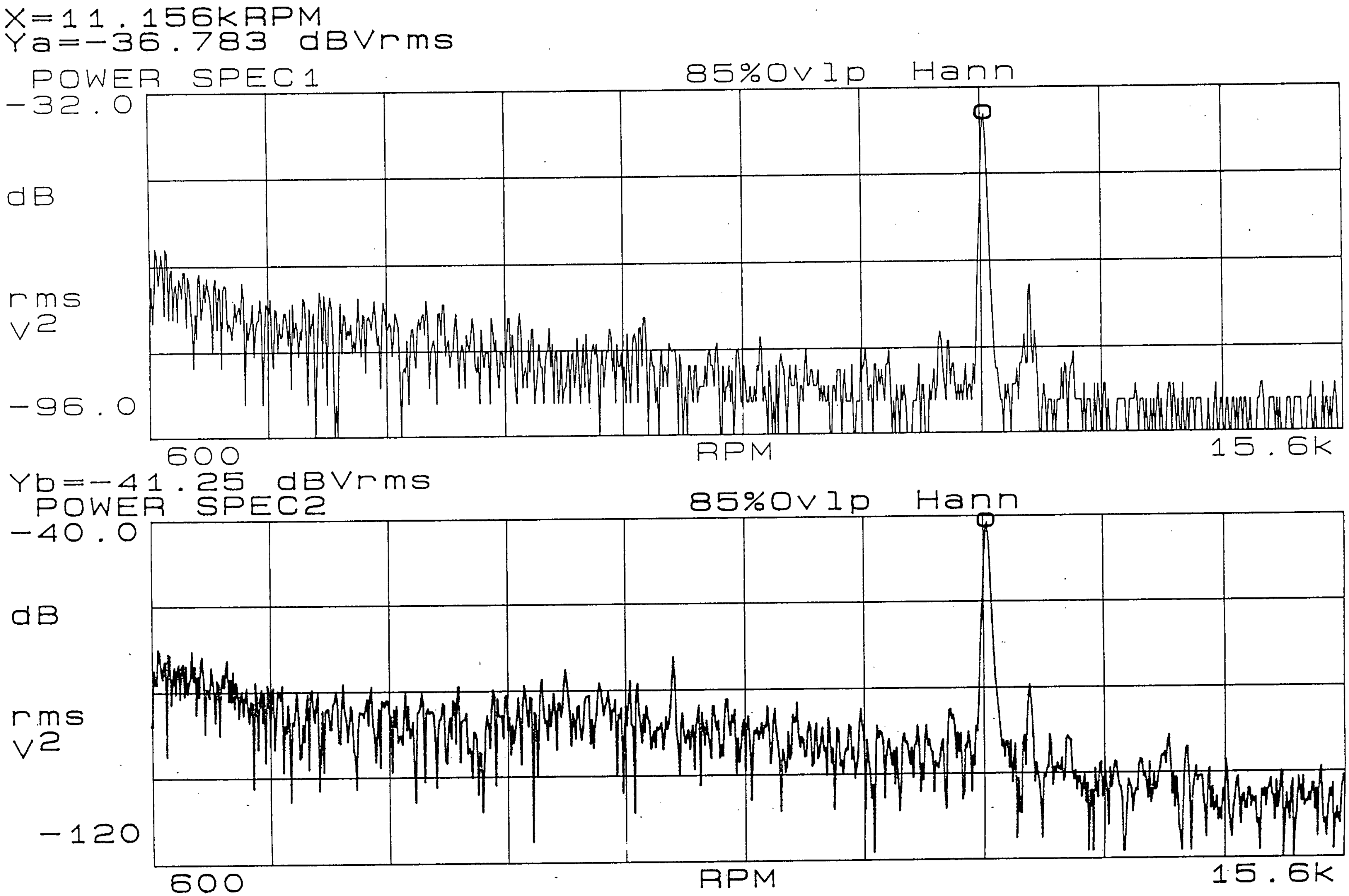
2-9

Run# -8-98-1



Run: 4-8-98-1

2-10


X=11.156kRPM
Ya=-36.783 dBVrms
POWER SPEC1
85%Ovlp Hann
-32.0
dB
rms
V2
-96.0
600
RPM
15.6k
Yb=-41.25 dBVrms
POWER SPEC2
85%Ovlp Hann
-40.0
dB
rms
V2
-120
600
RPM
15.6k

F #4-8-98-1

2-11

CALSTART: TEST DATA SHEET

DATE: 4/8

ITEM#	SPEED	TIME	CURRENT MONITOR MEASUREMENTS							
			X1		Y1		X2		Y2	
	Hz		Vdc	Vac	Vdc	Vac	Vdc	Vac	Vdc	Vac
	180	9:15 am	.28	.16	.18	.18	.04	.098	.39	.08
	160	9:15:48	.28	.88	-.07	.211	.039	.113	.356	.087
	135	9:16:44	~~[illegible]~~ .282	.197	-.070	.219	.040	.123	.399	.089
	120	9:17:20	.282	.193	-.070	.210	.040	.134	.399	.090
	110	9:17:55	.280	.185	-.069	.190	.040	.125	.399	.087
	95	9:18:43	.280	.145	-.070	.135	.039	.105	.399	.082
	85	9:19:23	.280	.125	-.069	.115	.039	.093	.399	.080
	75	9:20:01	.278	.082	-.069	.074	.039	.059	.398	.075
	65	9:20:56	.278	.064	-.069	.058	.039	.035	.399	.064
	55	9:21:48	.279	.041	-.069	.040	.039	.032	.399	.045
	50	9:22:01	.278	.038	-.069	.037	.039	.031	.400	.043
	40	9:23:20	.279	.023	-.068	.026	.041	.024	.402	.031
	30	9:24:26	.278	.017	-.069	.025	.040	.030	.401	.027
	25	9:25:05	.279	.014	-.069	.014	.041	.019	.402	.024
	20	9:25:44	.280	.013	-.069	.014	.044	.019	.404	.022

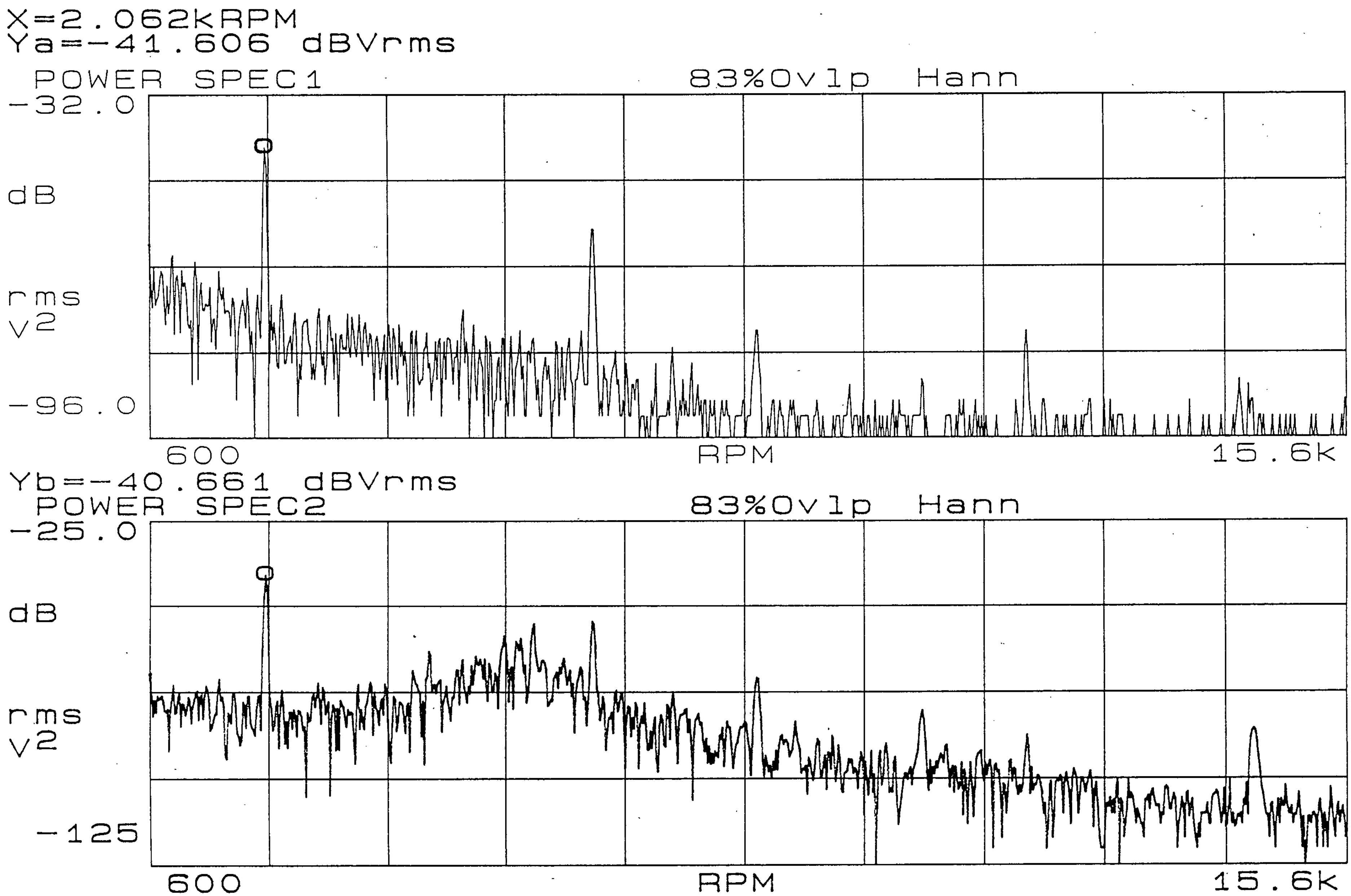
MOTOR STATUS: ☐ ENGAGED / ☐ DISENGAGED

DATA TAKEN BY: Mo

Starting speeding up again (even though motor was faulted but still turned on).

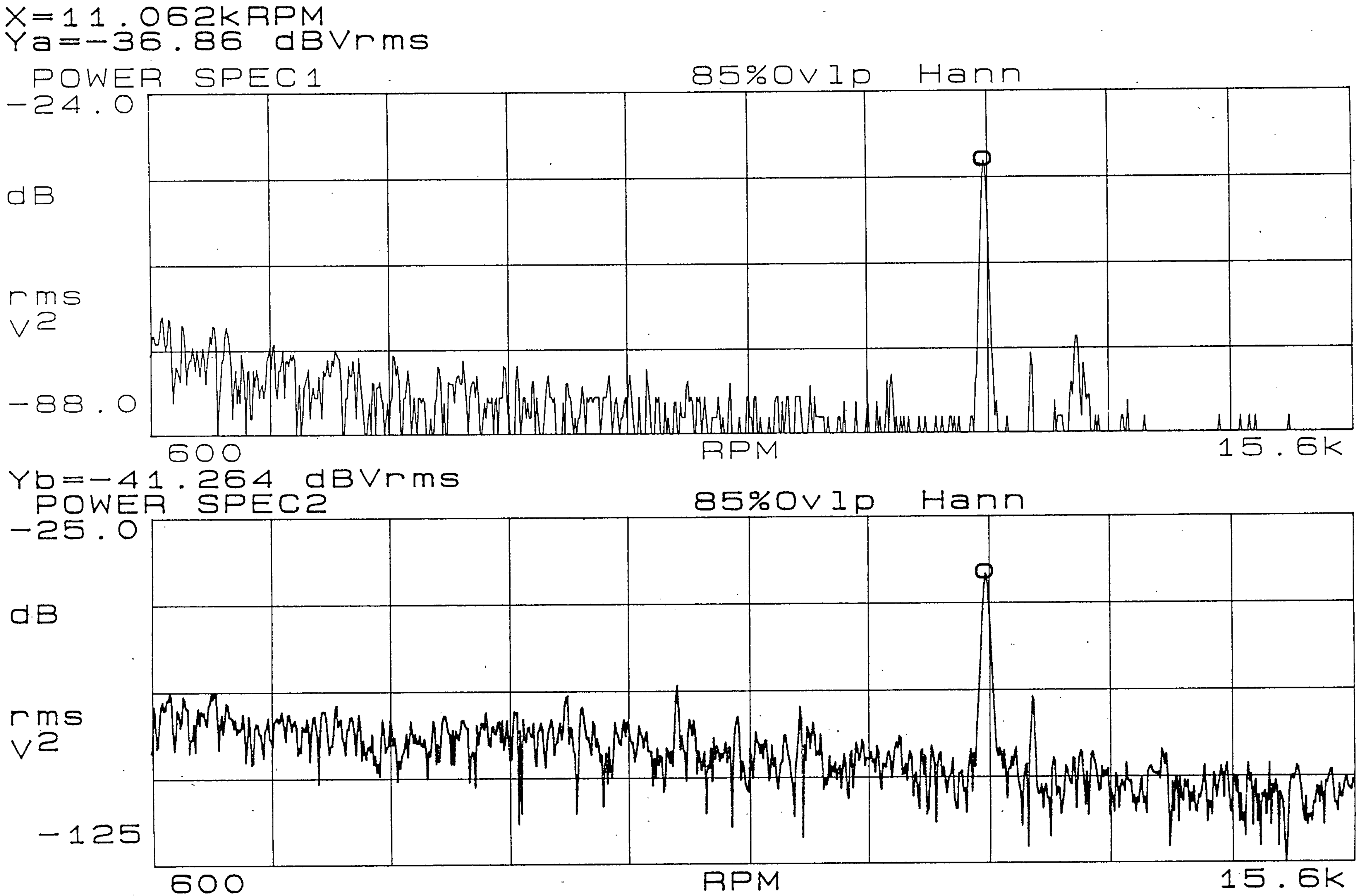
Run 4-8-98-2

2-12



Run 4-8-98-2

2-13


X=11.062kRPM
Ya=-36.86 dBVrms
POWER SPEC1
85%Ovlp Hann
-24.0
dB
rms
V2
-88.0
600
RPM
15.6k
Yb=-41.264 dBVrms
POWER SPEC2
85%Ovlp Hann
-25.0
dB
rms
V2
-125
600
RPM
15.6k

Run# 4. 2-98-2

CALSTART: TEST DATA SHEET

DATE: 4/8

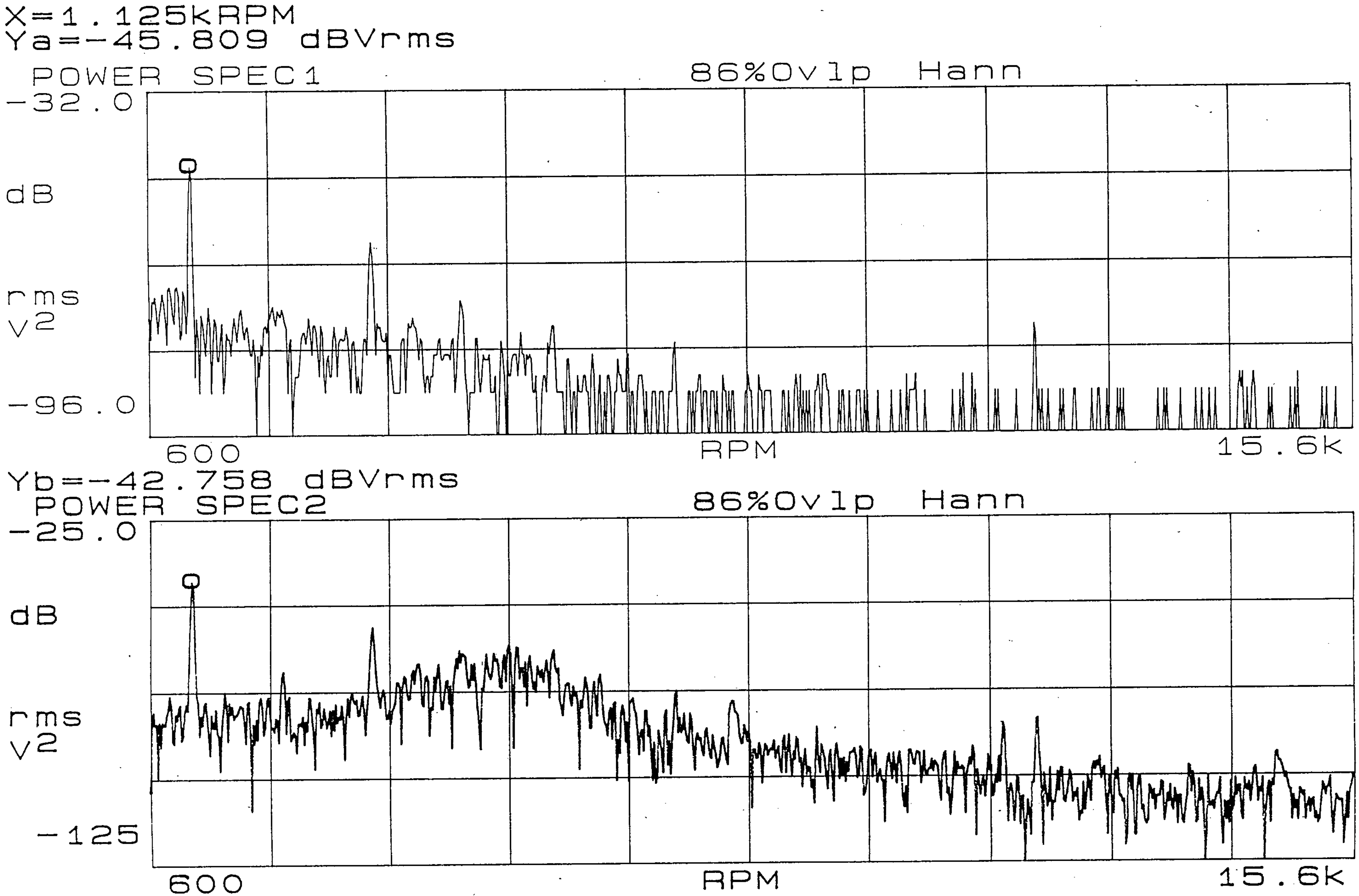
ITEM#	SPEED	TIME	CURRENT MONITOR MEASUREMENTS							
			X1		Y1		X2		Y2	
	Hz		Vdc	Vac	Vdc	Vac	Vdc	Vac	Vdc	Vac
	123	8:54 am	.28	.195	-.07	.208	.04	.127	.399	.088
	100	9:00	.281	.154	-.07	.146	.039	.109	.399	.085
	85	9:01	.279	.114	-.07	.10	.039	.08	.399	.08
	75	9:02	.28	.086	-.069	.076	.038	.061	.399	.075
	60	9:03	.277	.051	-.069	.047	.039	.036	.398	.051
	45	9:04	.278	.029	-.069	.03	.044	.025	.399	.035
	30	9:04	.277	.014	-.069	.018	.039	.021	.4	.024
	15	9:08	.282	.01	-.071	.01	.045	.015	.402	.018
	5	9:09	.288	.005	-.07	.006	.04	.006	.4	.007
		9:10	STOP							

MOTOR STATUS: ☐ ENGAGED / ☐ DISENGAGED

DATA TAKEN BY: Mohammed

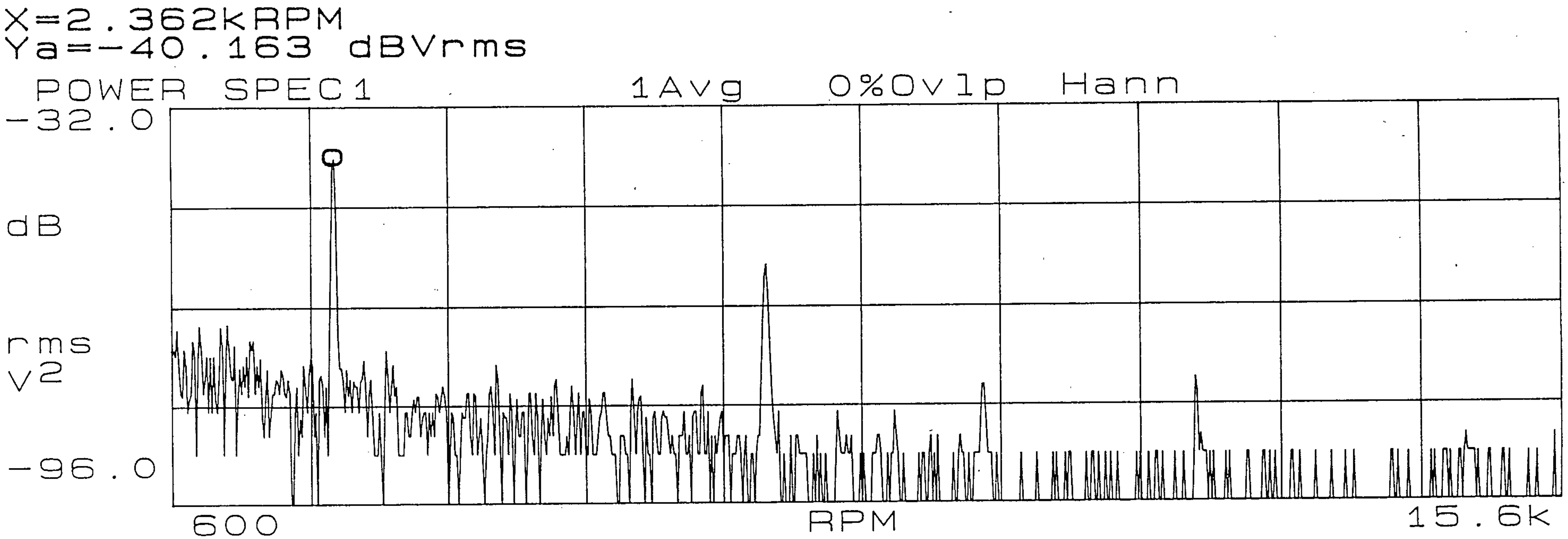
R. #4-8-98-3

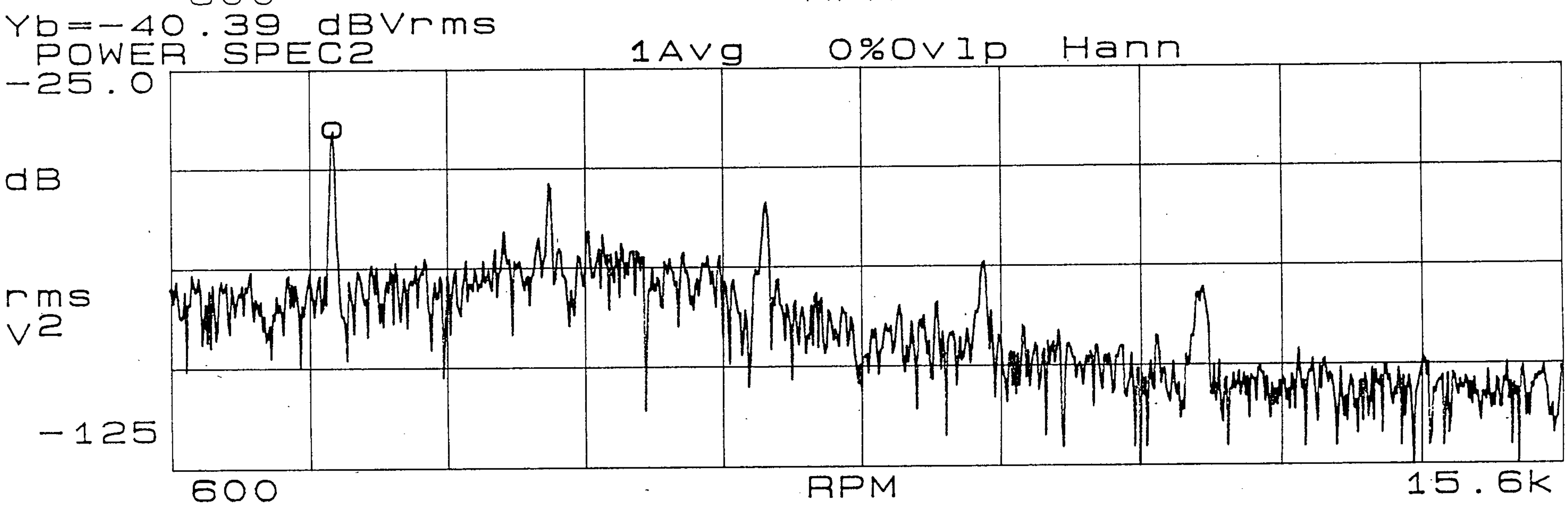
2-15



RUN#4-8-98-3

2-16





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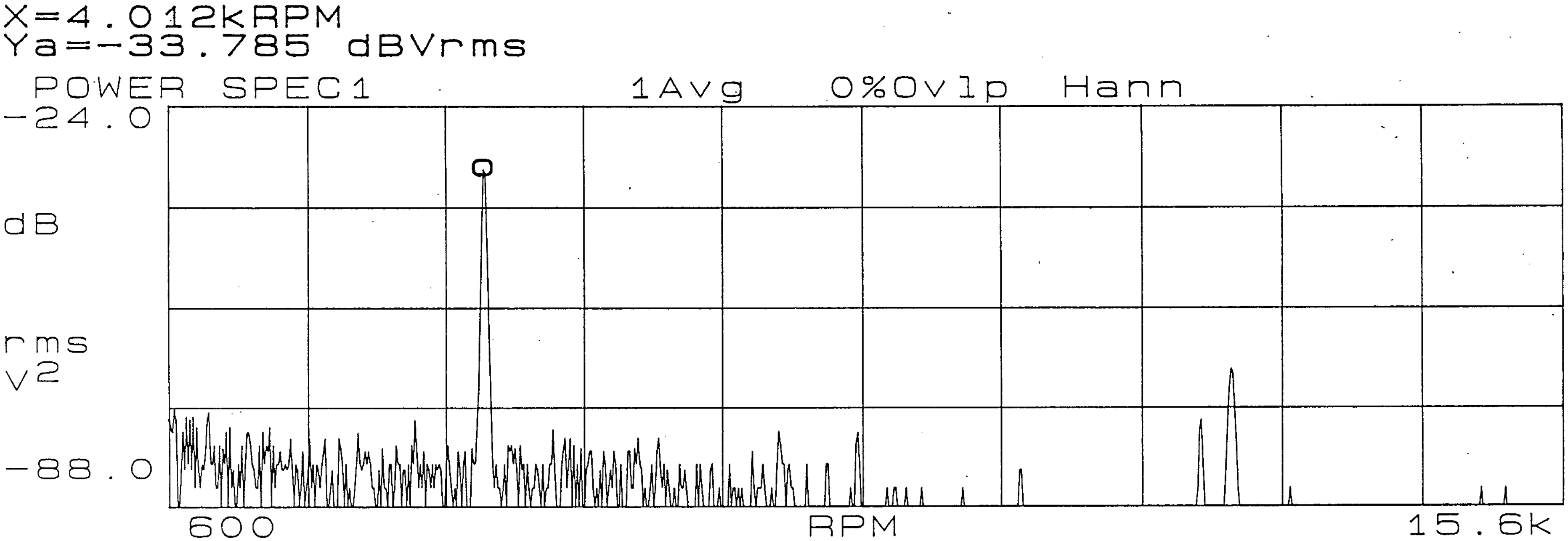
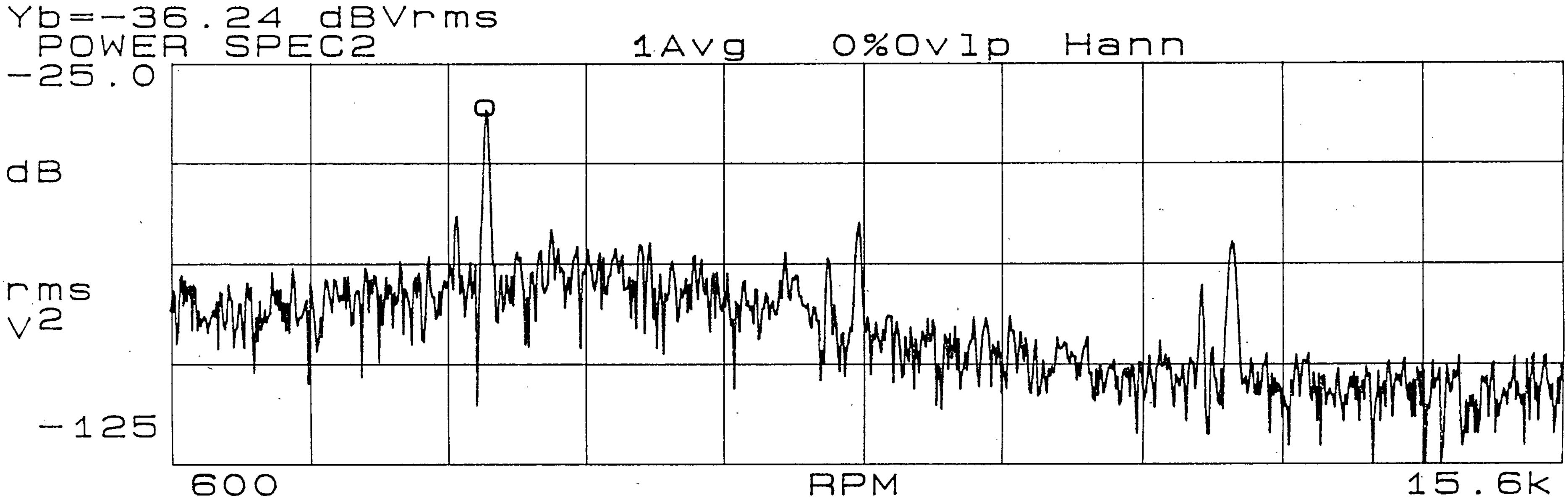
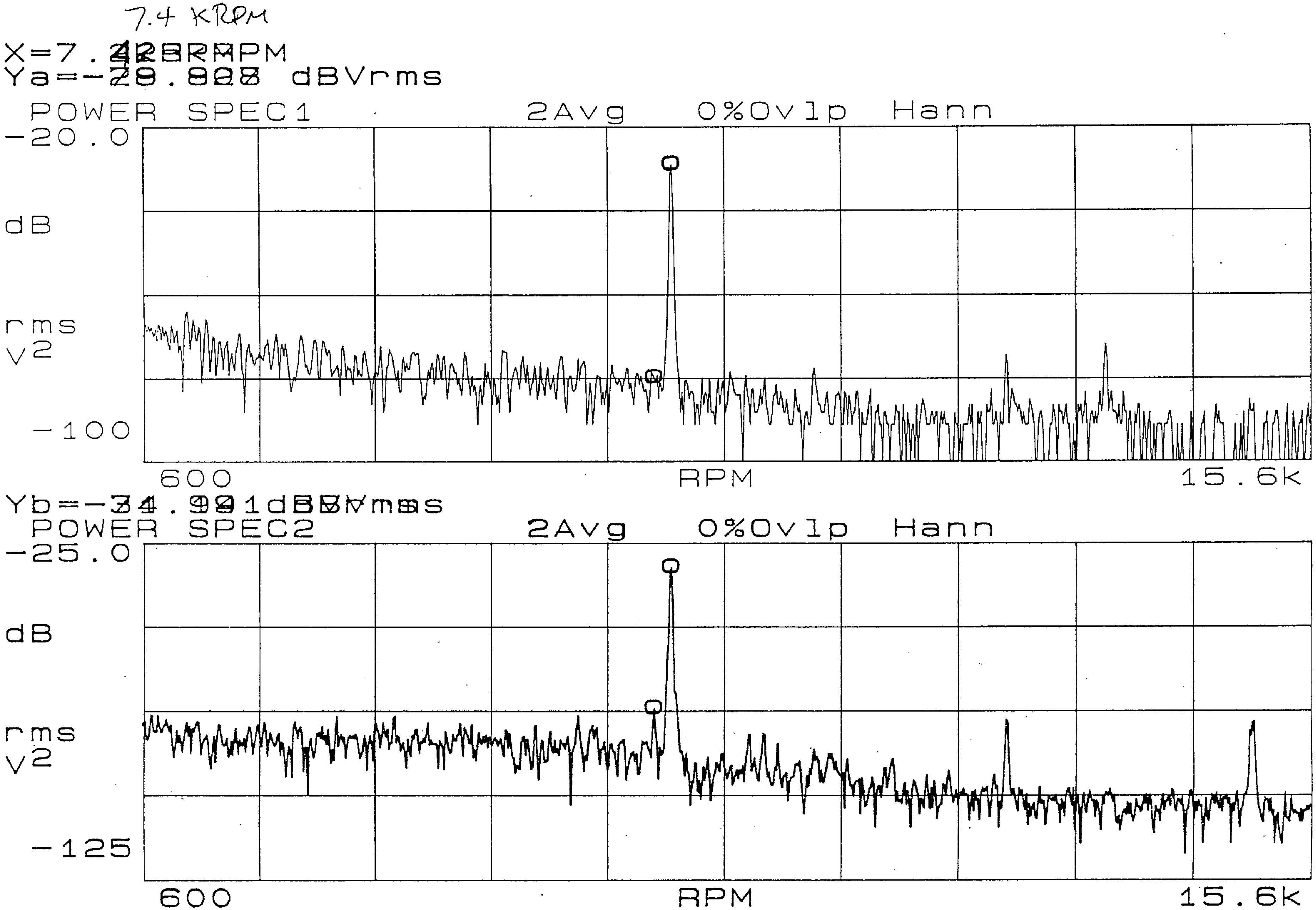
2-17





Run# 4-8-98-3

2-18



Run # 4 3-98-3

2-19

PREDICTERD RESULTS - WINDAGE								
n(rpm)	Cd1	Cd2	Cd3	Cd4	Cd5	wdot	dt	power
10000	0.00885	0.01396	0.00444	0.00531	0.00703	0.654	0	2.405
9500	0.00898	0.01421	0.00450	0.00537	0.00713	0.618	82	2.090
9000	0.00912	0.01449	0.00454	0.00544	0.00723	0.563	89	1.802
8500	0.00927	0.01478	0.00460	0.00551	0.00734	0.509	98	1.541
8000	0.00943	0.01512	0.00466	0.00559	0.00745	0.459	108	1.306
7500	0.00962	0.01546	0.00472	0.00567	0.00758	0.410	121	1.094
7000	0.00982	0.01585	0.00480	0.00577	0.00772	0.364	135	0.907
6500	0.01004	0.01628	0.00487	0.00587	0.00788	0.320	153	0.741
6000	0.01029	0.01677	0.00496	0.00598	0.00805	0.279	175	0.595
5500	0.01056	0.01733	0.00506	0.00611	0.00825	0.240	202	0.470
5000	0.01088	0.01797	0.00517	0.00625	0.00847	0.204	236	0.362
4500	0.01124	0.01872	0.00529	0.00642	0.00873	0.170	280	0.272
4000	0.01167	0.01961	0.00544	0.00661	0.00903	0.139	339	0.198
3500	0.01219	0.02068	0.00561	0.00684	0.00938	0.111	419	0.138
3000	0.01283	0.02203	0.00582	0.00711	0.00982	0.085	535	0.091
2500	0.01364	0.02379	0.00608	0.00746	0.01037	0.063	709	0.056
2000	0.01474	0.02623	0.00642	0.00792	0.01112	0.043	992	0.031
1500	0.01636	0.02991	0.00690	0.00858	0.01219	0.027	1504	0.014
1000	0.01908	0.03643	0.00767	0.00964	0.01397	0.014	2602	0.005
500	0.02545	0.05297	0.00931	0.01195	0.01797	0.004	5789	0.001

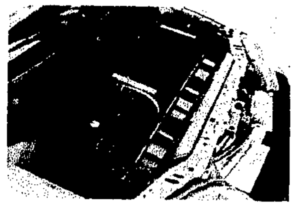
RUN #1									
time-sec	rpm	w	time-ave	alpha	w-ave	power-watts	rpm-ave	windage-watts	e-power
0	7800	816.8	30	2.618	738.274	6.784	7050	0.926	5.858
60	6300	659.7	96.5	1.721	596.903	3.607	5700	0.495	3.112
133	5100	534.1	167	1.386	486.947	2.369	4650	0.299	2.070
201	4200	439.8	226	1.257	408.407	1.801	3900	0.186	1.615
251	3600	377.0	280.5	1.065	345.575	1.292	3300	0.119	1.173
310	3000	314.2	340	1.047	282.743	1.039	2700	0.07	0.969
370	2400	251.3	405.5	0.885	219.911	0.683	2100	0.036	0.647
441	1800	188.5	480.5	0.795	157.080	0.439	1500	0.014	0.425
520	1200	125.7	563.5	0.722	94.248	0.239	900	0.004	0.235
607	600	62.8	630	0.683	47.124	0.113	450	0.001	0.112
653	300	31.4	681.5	0.551	15.708	0.030	150	0	0.030
710	0	0	355	0.000	0.000	0.000	0	0	0.000

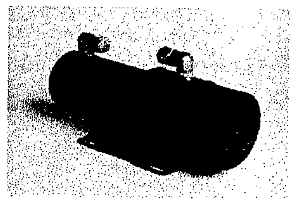
CALSTART

Defense Advanced Research Projects Agency
Cooperative Agreement MDA972-95-2-0011
and modifications through P00012
Quarterly Report
January 1 to March 31, 1998

APPENDIX

GLACIER BAY
FINAL REPORT





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GLACIER BAY ENVIRONMENTAL CONTROL SYSTEM FOR ELECTRIC AND HYBRID VEHICLES (ECS) FINAL REPORT APRIL 1998

Glacier Bay Environmental Control System for Electric and Hybrid Vehicles (ECS)
Calstart/DARPA FY '96

Final Report
April 10, 1998

Introduction

The mobile heating and air conditioning systems in use today on internal combustion vehicles do not lend themselves to efficient application in the EV market. To date, numerous attempts have been made to try to adapt these systems by making rudimentary changes in one or two of the primary components. In a through analysis of these adapted systems, EPRI (Air Conditioning For Electric Vehicles, TR-102657) found them to be both underpowered and remarkably inefficient. The most efficient unit tested averaged an EER (Energy Efficiency Ratio, BTU/hr output divided by watts input) of only 6.17. This means that it required 30% more energy than would be expected of a common home window air conditioner.

While the air conditioning systems were proving problematic, the heating systems were not much better. This was particularly true for purely electric vehicles which were relying on either electric "heat pump" systems or, fossil-fueled forced-air systems designed as supplemental heaters for trucks and boats. A report issued by M.J. Bradley and Associates, following extensive heater testing by the Northeast Advanced Thermal Management Project found all but one heater to wholly inadequate to the task of properly heating Geo Metro in a Northeast winter climate. None of the systems tested could be integrated into the air conditioning system and all systems tested were found to be overly complex and too large to easily install.

With an emerging EV market, the need for a powerful, efficient, purpose-built EV environmental control system is apparent. Under a co-operative funding grant from DARPA (administered through Calstart), Glacier Bay began the work of applying the high-efficiency cooling technologies, which Glacier Bay had previously applied to the marine industry, to the development of a system that would fulfill this need. The result was the Glacier Bay Environmental Control System for Electric and Hybrid Vehicles (ECS).

Project Goals

The original goals of the project were;

Dramatically reduced energy consumption - Preliminary computer modeling and proof-of-concept testing indicated that the Glacier Bay Environmental Control System would operate at an EER of 11.22 under severe driving conditions and 15 under average conditions. At these levels of efficiency the Glacier Bay Environmental Control System for EVs would require 55%

less energy than best EV air conditioning systems available. Under the same operating conditions, the most efficient vehicle air conditioning system identified in EPRI's investigation (Air Conditioning Systems for Electric Vehicles, EPRI-TR102657) averaged an EER of only 6.17.

Reduced space requirement and lighter weight - Through the use of a small displacement, high-speed integrated compressor and high efficiency condenser/ evaporator designs, a reduction of 50% in the total size and weight of the system was projected.

Reduced maintenance and improved reliability - Leaking fittings as well as moisture and gas permeation of rubber hoses are the leading contributors to poor reliability of automobile air conditioning systems. By designing the Glacier Bay ECS as the first 100% hermetically sealed vehicle environmental control system, the refrigerant leaks, moisture contamination, brush wear and belt adjustments which plague existing systems would be eliminated entirely.

Increased heat output in cold climates - Based on research done by EVermont and others, it was determined that a minimum heater output of 5 kw (17,000 Btu/hr) would be required. The fossil-fuel fired heater would be compatible with both propane and natural gas providing much lower emissions than that of diesel-fired heaters.

Easily and inexpensively adapted to a wide range of voltage inputs - The system would be easily produced for operation from a wide range of input voltages thus effectively eliminating this restricting factor in capturing the low-volume production markets.

Accomplishments

Following is a point-by-point tally of the project's success in meeting the originally established goals;

Dramatically reduced energy consumption - Glacier Bay Environmental Control System achieved an EER of 11.36 under severe driving conditions and 15.80 under average conditions thus exceeding the original program goals by 5%.

Reduced space requirement and lighter weight - The Glacier Bay ECS components total 60.82 lbs. When compared with a typical combined heating and air conditioning system weight of 122.3 lbs[1] , the ECS represents a weight reduction of 51.3% thus meeting the project goal.

Reduced maintenance and improved reliability - The Glacier Bay ECS successfully achieved a 100% hermetically sealed design, thus meeting this goal.

---

[1]Typical system weights were obtained from the average of all air conditioning systems tested by Arthur D. Little [EPRI-TR-102657s] and heating systems tested by the Northeast Advanced Thermal Management Project.

Increased heat output in cold climates - The Glacier Bay ECS achieved an output of 5.97 kw (20,361 Btu/hr) in a liquid circulating, fossil-fuel fired heater design thereby exceeding the original goals with a 19% over-capacity. Additionally, the heater was demonstrated to be compatible with both propane and natural gas fuels.

Easily and inexpensively adapted to a wide range of voltage inputs - In its final design, the Glacier Bay ECS is a system which can be easily produced for operation at any input voltage from 98 to 425 vdc. Adaptation to various voltages is accomplished through with a wide input voltage motor controller. To match any input voltage in the operating range requires only that the correct motor windings be used. This ease of production customization meets the original goal.

Review of work performed

The broad purpose of the work in this project was to successfully adapt Glacier Bay high-efficiency DC technology to an environmental control system suitable for the electric vehicle market. To apply this adapted technology in a complete fully-operational system, and to demonstrate that system in two sets of independently documented tests. To this end, the work was divided into three task areas;

Task 1 - Design and production of the major system components
Task 2 - Design and production of installation-specific system components
Task 3 - Performance testing

Specifically, the work performed in the individual task areas was;

Task 1 - Design and production of the major system components
The major system components referred to cover four specific items.

- Compressor and Motor
- Condenser and Evaporator/Heat Exchanger
- Heating Unit
- System Controller

Compressor and Motor -
The compressor and motor used in the Glacier Bay ECS were built specifically built components. The compressor was 100% hermetically sealed and of a rolling piston design built by Glacier Bay, Inc. The motor was a 12-pole brushless DC design built for Glacier Bay by MFM Motors.

Condenser and Evaporator/Heat Exchanger -
The Condenser and the Evaporator/Heat Exchanger were designed and built by Glacier Bay for

otherwise identical, Geo Metro equipped with factory-installed engine-driven air conditioning system were left in full sun-soak in the parking lot all morning. In early afternoon, at maximum ambient air temperature, the two cars (each with one driver only) were driven out of the parking lot and followed each other through the surrounding streets. Driving speeds averaged approximately 45 mph and included several stop signs, stop lights and intersections.

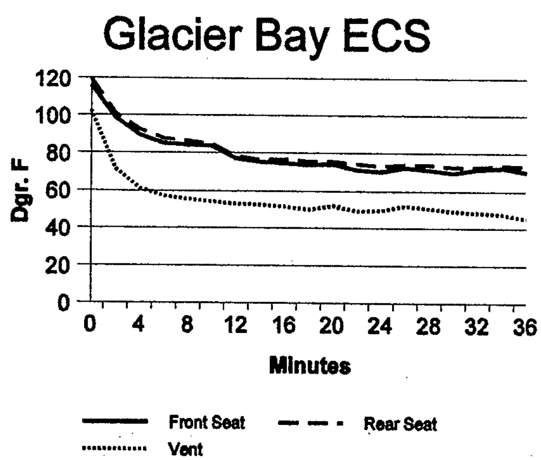
Ambient Conditions -
At the time of the test, the ambient conditions were;

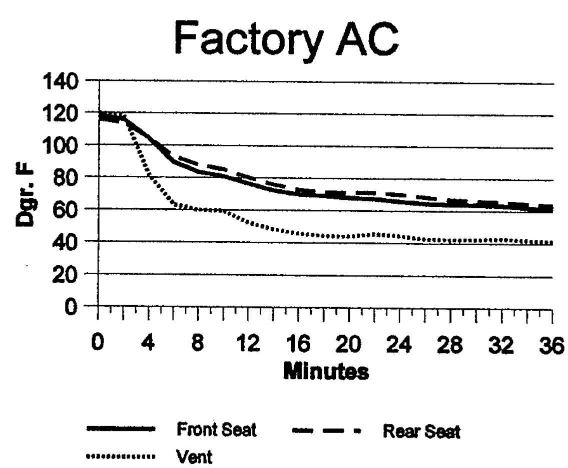
Temperature - 91^{0}F
Solar Radiation - 760 W/sq m
RH - 51%
Wind Speed - 4 m/s

Sensor Locations -
In each vehicle, a total of ten Sensors were installed at the following locations:

(a) One at the outlet of the 2 main dashboard blower vents - total 2
(b) One at 31" above the seat (i.e. head position) in both the front and rear - total 4
(c) One at 14" above the seat (i.e. stomach position) in both the front and rear - total 4

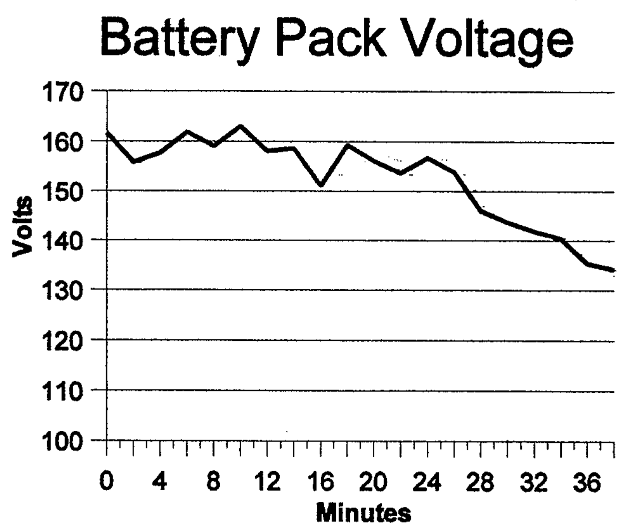
Data Readings (exhibit 2a, 2b) -
Data was logged every two minutes. The charts below give an average reading of the four sensors in each seat to provide a "Front seat" and "Rear Seat" temperature. The two dash board readings were averaged to give the "Vent" temperature.





Data Analysis (Exhibit 3a, 3b) -
An analysis of the results shows the Glacier Bay ECS and Geo Metro factory engine-drive air conditioning to be very similar in cooling capacity. Both units cooled the passenger compartments from 120^0 F to 75^0 F in twelve minutes. Similarly, both units were able to maintain comfortable cabin temperatures under full solar load and at all vehicle speeds.

Negating the effect of voltage drop (Exhibit 4) -
One problem well-know in previous tests of electric air conditioning systems which were being powered directly from the vehicle battery pack was a dramatic reduction in system capacity as the battery voltage falls. This was a potential problem of special concern to Glacier Bay when developing the ECS control system. For this reason particular attention was paid to ensuring that system output remained as steady as possible through the discharge and regenerative braking cycle of the battery pack. A close look at the battery voltage reveals that the input voltage fluctuated by almost 20% (30 volts) without substantial impact on the ECS system capacity.



Conclusion -
The ECS air conditioning system performance matched, and in some ways exceeded, that of the factory-installed engine driven air conditioning system. The ECS was able to control the temperature of the cabin to full passenger comfort at freeway speeds and very high heat loads. While further tests are necessary, the test performed indicates that the ECS would have offered superior performance in heavy traffic conditions, where lower engine speed would limit the air conditioning system capacity of the factory unit.

While no direct measurements were taken during this test run, it is know from tests of similar engine-driven systems[2] and the bench-top efficiency tests of the ECS, that this level of performance was achieved with only about 25% as much energy input.

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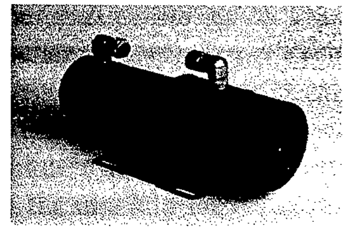
[2]Air Conditioning System for Electric Vehicles, Arthur D. Little, Inc. # EPRI TR-102657s

Phase 2 - Heating



The ECS heating system test was performed on March 20, 1998 by Professor Andrew Frank of the Department of Mechanical Engineering at the University of California at Davis. Extensive previous testing had been already been conducted to determine the heating requirement of the Solectria Force test vehicle[3]. With the heating requirement of the car so well established, the intent of the U.C. Davis testing was to quantify the heat output and emissions of the Glacier Bay ECS system. The system was tested using natural gas fuel.

Test Protocol (Exhibit 5) -
U.C. Davis ran two separate tests for the ECS heating system. In the first test, a positive displacement water pump was used to circulate a constant, known mass flow of water through the heating unit. Thermocouples recorded the Delta T between the incoming and outgoing water to determine the rise. From this the heat output could be determined.

The purpose of the second test was to determine the emissions during steady state operation. For this test the heater was connected to a finned coil air heat exchanger so that a stable steady-state condition could be achieved at normal operating temperatures. The heater was activated and the discharged exhaust gas analyzed by a 5-gas emissions analyzer.

Test Result - Capacity (Exhibit 6)

Mass flow rate: 1,454.4 lbm/hr
Delta T: 14^{0} F
Heating Capacity: 5.97 kw (20,361 Btu/hr)

Test Result - Emissions (Exhibit 6)
The following emissions were recorded for the Glacier Bay ECS heating system in steady-state operation:

Nitrous Oxides, NOx:	24 ppm
Carbon Monoxide, CO:	0.12%
Hydrocarbons, HC:	3 ppm
Carbon Dioxide, CO_2:	6.1%

[3]Northeast Advanced Thermal Management Project, M.J. Bradley and Associates

For comparative purposes, the tested emissions of a common competitive heating system are shown below[4]:

Brand:	Webasto
Fuel:	Diesel/Kerosene
Nitrous Oxides, NOx:	200 ppm
Carbon Monoxide, CO:	0.2%
Hydrocarbons, HC:	100 ppm
Carbon Dioxide, CO_2:	10.5%

Conclusion -
The Glacier Bay ECS heating system exceeds the performance goals set forth at the time of the project proposal. With a capacity of over 20,000 Btu/hr it has higher capacity than any auxiliary heating system tested by the Northeast Advanced Thermal Management Technology Project. In fact, it matches that of water-circulating heaters in modern combustion engine cars. As such, the heater would provide complete passenger comfort at temperatures of -25^0 F in any automobile or cargo van while retaining sufficient capacity for de-fogging all windows. With its full heat output "instantly available", the Glacier Bay ECS heater provides a distinct advantage over the engine-coolant heaters of today's gasoline cars.

Technology Commercialization

The target markets for the Glacier Bay ECS and its related technology has been identified as:

- Electric and hybrid car OEMS. - US & Foreign
- Electric and hybrid bus OEMS - US & Foreign
- Electric and hybrid vehicle fleet operators
- High-End electric vehicle conversions
- US Government - military climate control in vehicles and portable equipment

Since the third quarter of 1997 Glacier Bay has undertaken a program of "low-key" promotion prior to formal introduction of the system. Additionally, individual technologies and system components were shown at the 1997 EVS-14 trade show in Orlando, Florida.

The result of these modest promotions have indicated the existence of a robust and growing market for the technology. As of this writing Glacier Bay has received purchase orders for high-capacity versions of the system from a prominent transit bus manufacturer. Additionally, Glacier Bay has received numerous inquires from European and Asian automobile manufacturers for developmental prototypes.

[4]Northeast Advanced Thermal Management Technology Project, M.J. Bradley and Associates. Of five heaters tested only the Webasto (shown) and one Espar were capable of properly heating the vehicle. The Webasto had the lowest emissions of the two.

Within three months time Glacier Bay, will begin shipping its first 70,000 Btu/hr ECS transit bus systems. These will be followed quickly by a 120,000 Btu/hr system scheduled for late summer delivery.

In fall of this year, Glacier Bay will formally introduce the complete ECS system at EVS-15 in Brussels, Belgium.

Future Enhancements

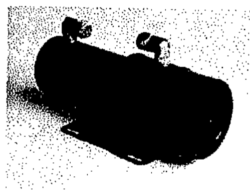
During the course of the past 1.5 years of development work on the Glacier Bay ECS, three major enhancements have been identified for the system. These are;

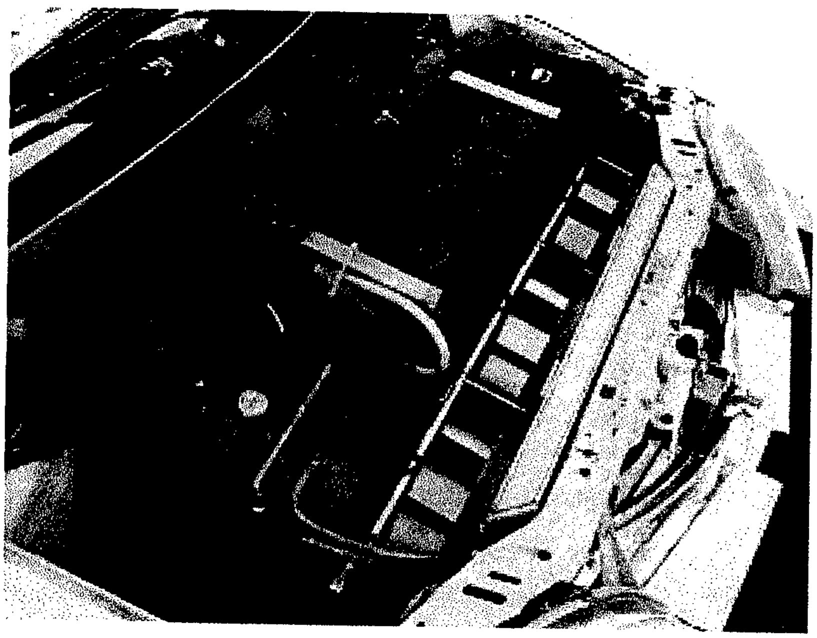
Development of a Back-EMF Brushless DC Motor Controller -
This controller will replace the hall-sensor control now used on the ECS. The new controller will reduce system cost and complexity, simplify installation, improve reliability and reduce size. Development co-funding of this controller is currently before DARPA and pending final review for FY '98. The development project will be conducted jointly with IBM Corporation and utilize the company's patented technology.

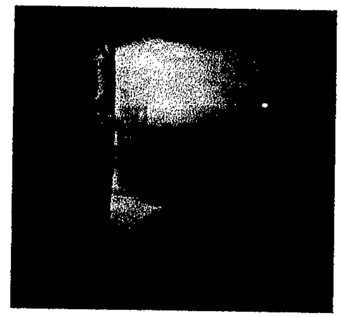
Incorporation of a Variable Capacity-Controlled Burner -
This development project calls for the current ON/OFF type burner to be replaced with one of variable steady-state capacity. This improved burner technology will further reduce emissions by allowing the system to always operate at a steady thermal condition. Additionally, the burner will provide lean-burn capability further improving the heater's efficiency and reducing fuel consumption. Development co-funding of this controller is currently before DARPA and pending final review for FY '98.

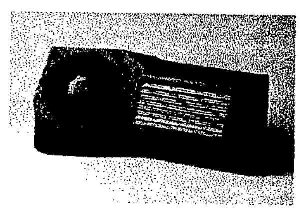
Development of a High-Efficiency Flooded Evaporator -
The successful development and inclusion of a high-efficiency flooded evaporator would enable Glacier Bay to break the 400 fpm air velocity limit which effectively prevents substantial further reductions in evaporator size. Work on the evaporator is currently underway in Glacier Bay's R&D department.

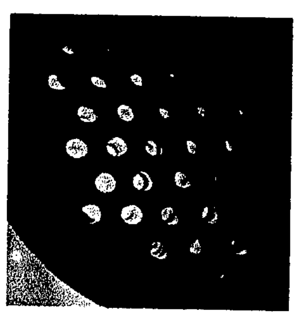
EXHIBITS











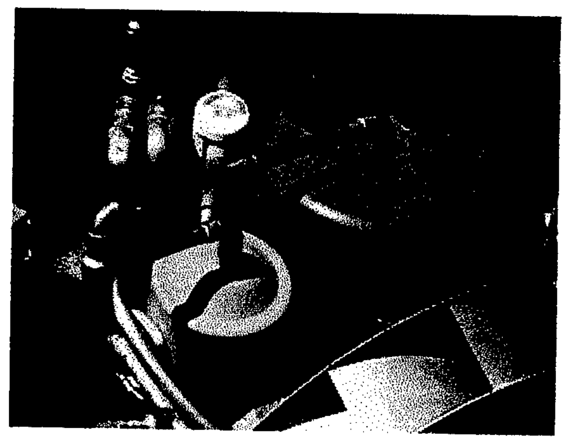


EXHIBIT 1a

EV10 A/C Test Run
FSEC

September 17, 1997
Julian Day 1997-260

Start of first loop 14:52

Time	Miles	Location
14:52	0	Exit FSEC onto Michigan Ave to Clearlake Road heading south Behind school bus and school zone traffic slow, stop-go
15:01	2.5	Right onto 520 West open highway
15:04	4.6	Right onto Cox Road North open road
15:07	6.4	Right onto 524 East open road
15:10	8.7	Right onto Clearlake South
15:11	9.3	At Michigan light FSEC
End 1st Loop		
15:11	9.3	Clearlake South no school traffic
15:17	11.6	Left 520 East
15:20	13.0	Left US-1 North
15:29	19.5	U-Turn US-1 South (batteries getting low)
15:36	23.4	Right onto Michigan West
15:38	23.8	FSEC
End 2nd Loop		

EXHIBIT 1b

EV10 A/C Test Run FSEC

Sept 17, 1997
Julian 260

1st Loop 9.3 miles
14:52 - 15:11

2nd Loop 14.5 miles
15:11 - 15:38

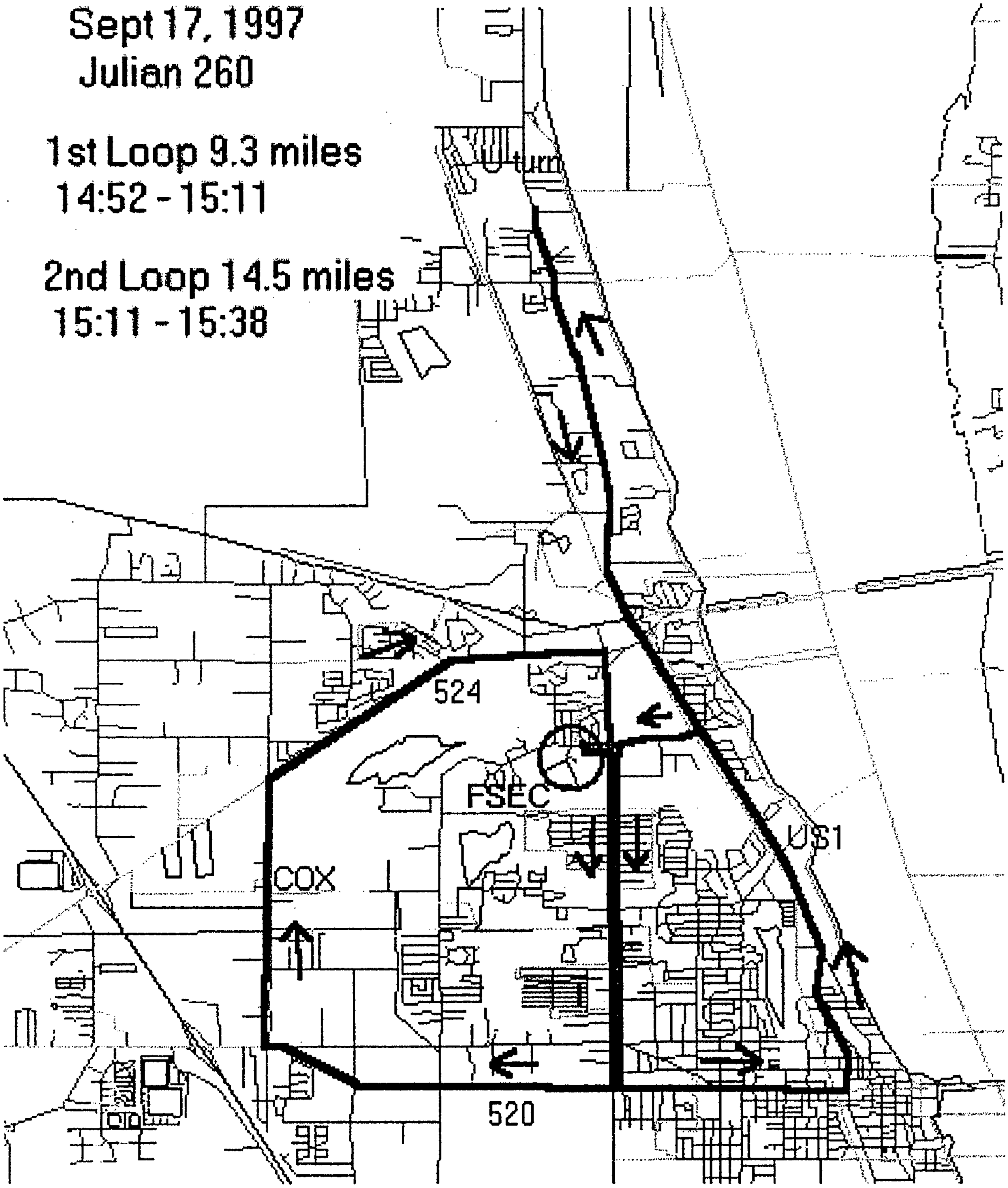


EXHIBIT 2a

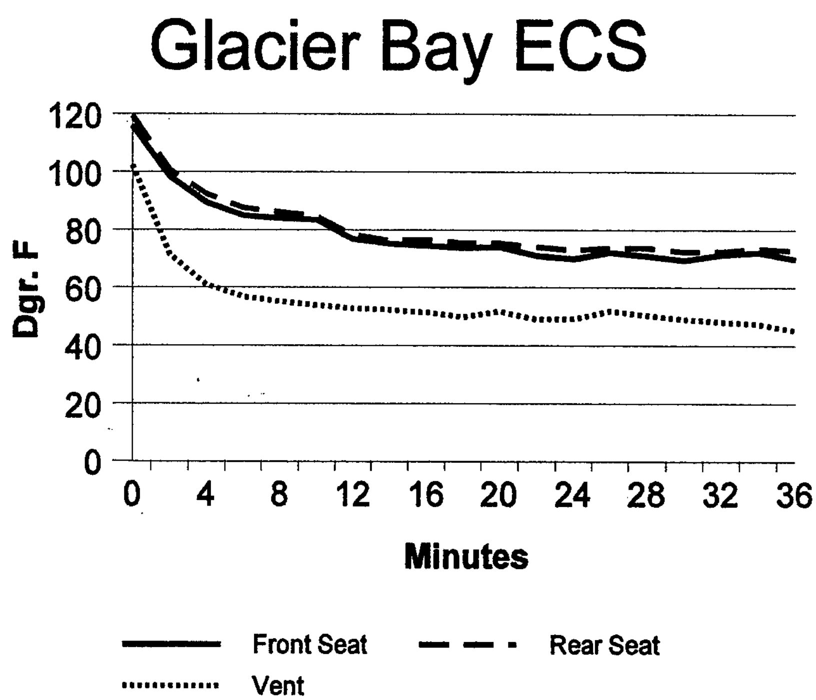
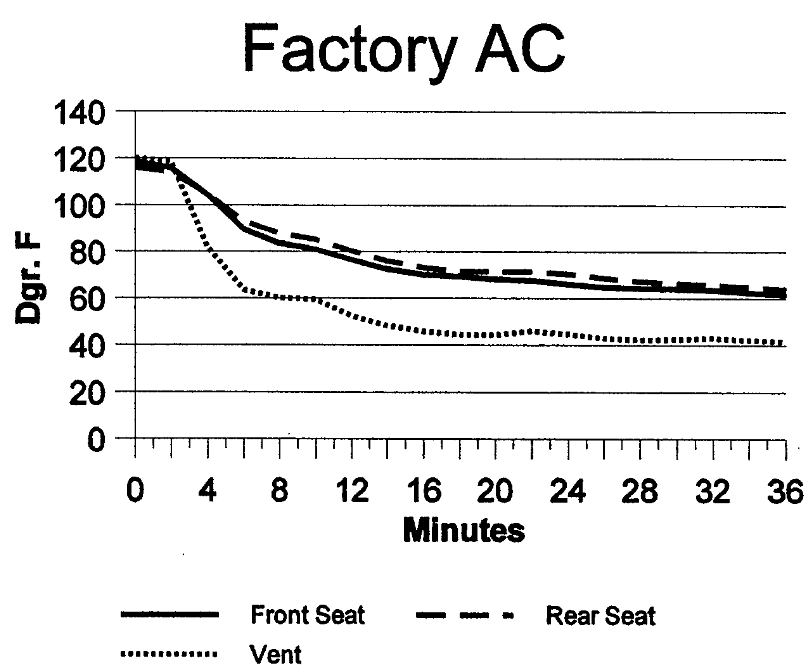


EXHIBIT 2b



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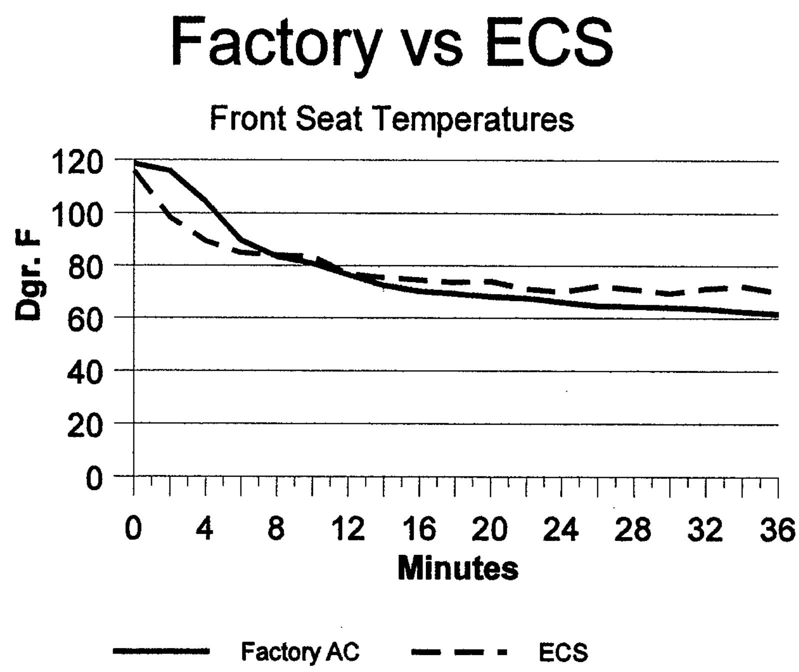


EXHIBIT 3b

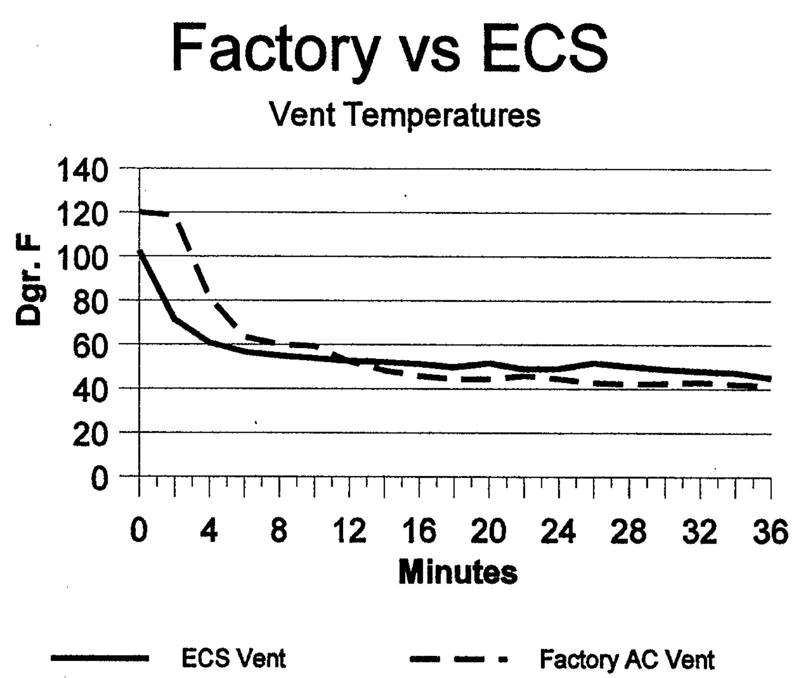
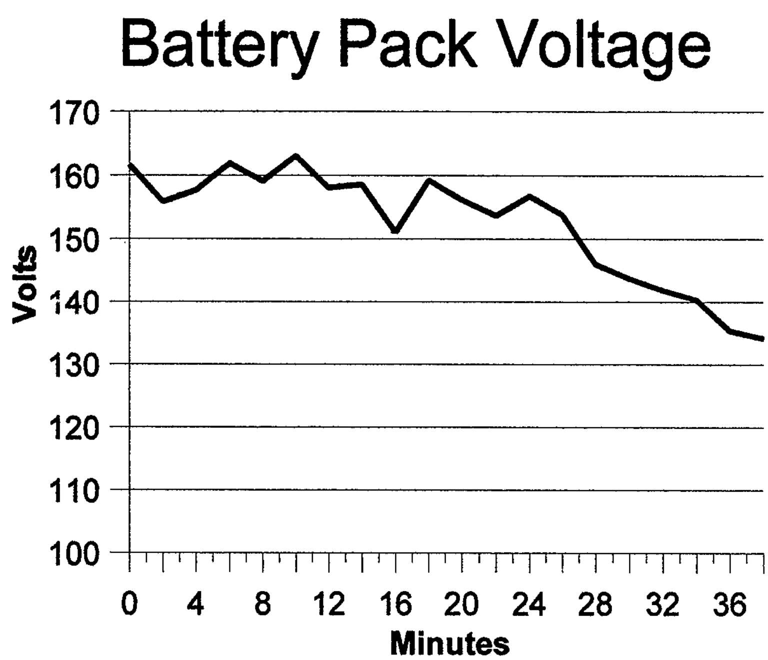
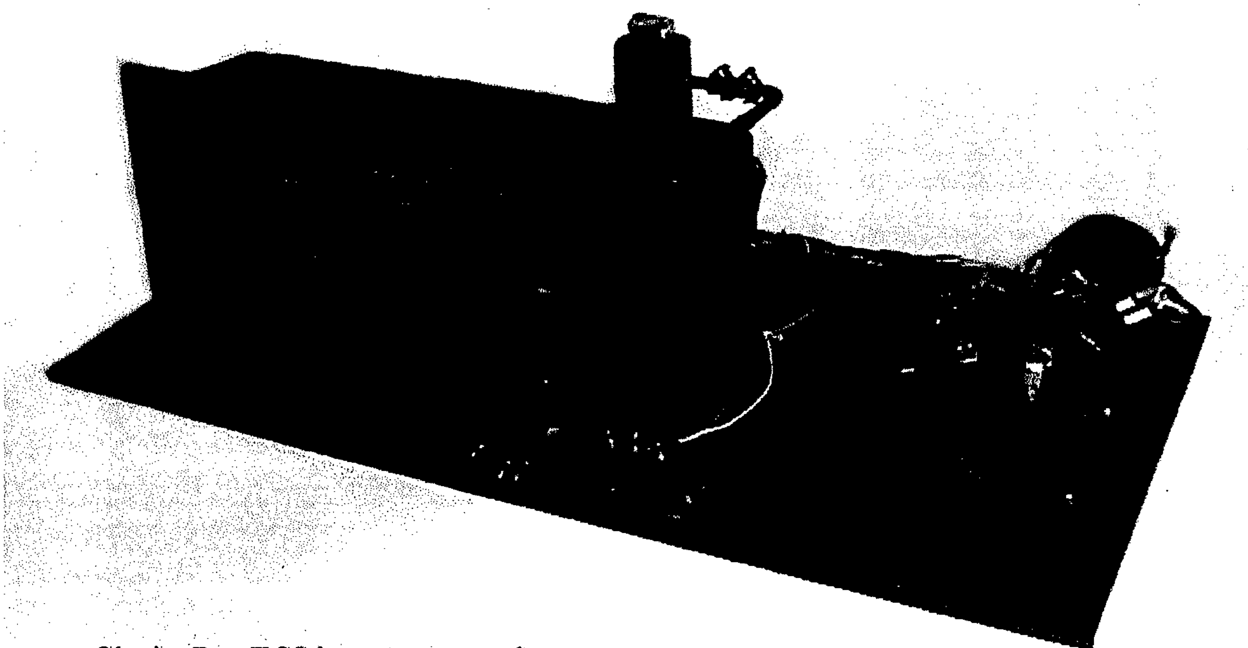


EXHIBIT 4



Battery Pack Voltage
170
160
150
140
130
120
110
100
Volts
0
4
8
12
16
20
24
28
32
36
Minutes

EXHIBIT 5



Glacier Bay ECS heater test stand.

EXHIBIT 6

UNIVERSITY OF CALIFORNIA, DAVIS

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO

SANTA BARBARA • SANTA CRUZ

COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL AND
AERONAUTICAL ENGINEERING
(916) 752-0580
FAX (916) 752-4158
http://www-mae.engr.ucdavis.edu

DAVIS, CALIFORNIA 95616-5294

Professor Andrew Frank
Department of Mechanical Engineering
University of California
One Shields Avenue
Davis, CA 95616

March 23 1998

Kevin Alston
Glacier Bay, Inc.
1011 Claremont St.
San Mateo, CA 94402

Dear Mr. Alston:

Listed below are the test results of the compressed natural gas combustion water heater. This verification testing was performed at UC Davis on March 20, under Agreement No. 98-00344V.

The 5-gas emissions analyzer recorded the following data at steady-state operation:

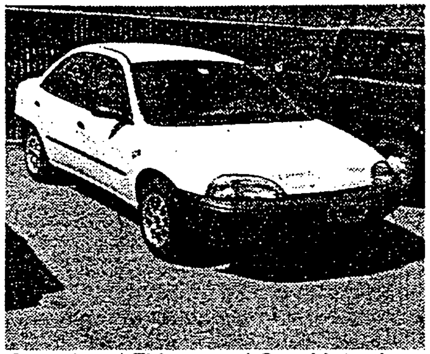
Nitrous Oxides, NOX:	24	[ppm]
Carbon Monoxide, CO:	0.12	[%]
Hydro Carbons, HC:	3	[ppm]
Carbon Dioxide, CO2:	6.1	[%]
Oxygen, O2:	9.7	[%]

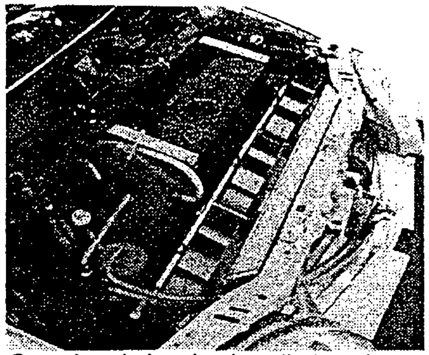
The measured water mass flow rate is:	1454.4	[lbm/hr]
Average water temperature difference at steady-state is:	14	[°F]
The resulting heat capacity of the system is calculated at:	20,361	[BTU/hr]

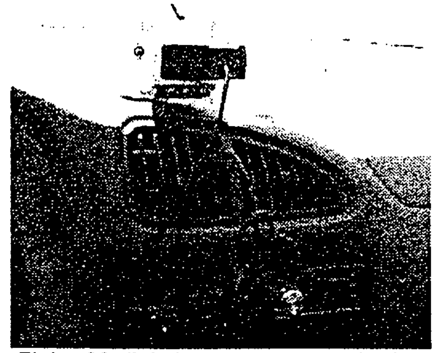
Please contact me at (530) 752-8120 for any questions regarding this testing project. Thank You.

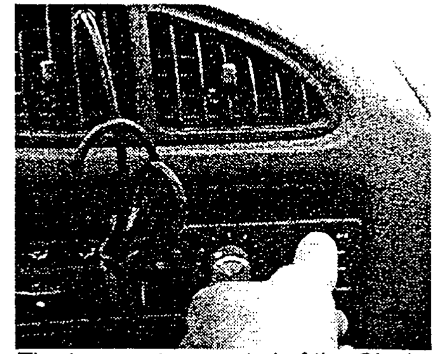
Sincerely,

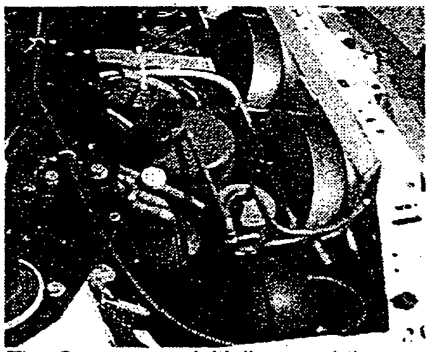
ANDREW FRANK
Principle Investigator

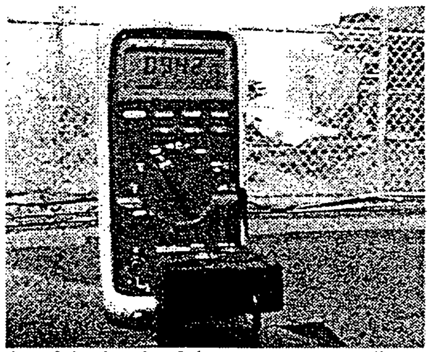

Completed EVermont / Geo Metro in full sun-soak prior to the start of the test.

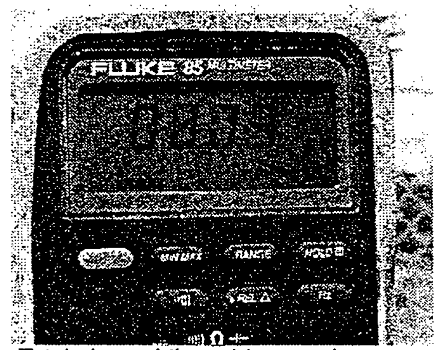

Open hood showing installed equipment. Compressor, Receiver and Condenser Blowers are clearly visible.


Fluke 86 digital temperature probe is installed to monitor and visually indicate the driver's vent air temperature.


The temperature control of the Glacier Bay ECS is set to full power and the unit is turned on.

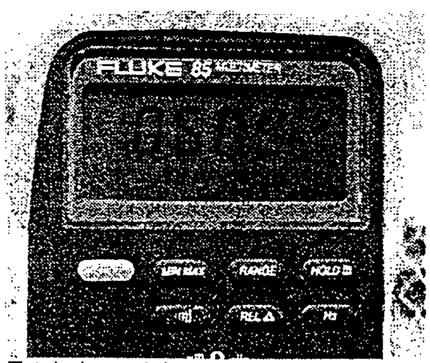

The Compressor initializes and the Condenser Blowers begin to spin.


A quick check of the temperature display shows the starting temperature to be 94.2 degrees F.

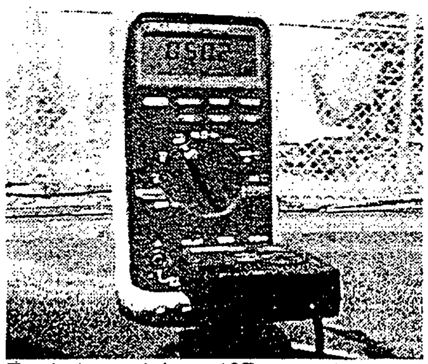


Total elapsed time: 14 seconds.
The vent air temperature has fallen to 80.3 degrees F.

Total elapsed time: 28 seconds.
The vent air temperature has fallen to 70.0 degrees F.



Total elapsed time: 61 seconds.
The vent air temperature has fallen to 60.0 degrees F.


Total elapsed time: 127 seconds.
The vent air temperature has fallen to 50.2 degrees F.

Glacier Bay, Inc.
Environmental Control System for Electric & Hybrid Vehicles (ECS)

This series of still images is taken from a videotaped test of the Glacier Bay ECS in San Mateo California on 8/5/97, the day before the car was shipped to the Florida Solar Power Research Institute where it underwent further testing.

Defense Advanced Research Projects Agency
Cooperative Agreement MDA972-95-2-0011
and modifications through P00012
Quarterly Report
January 1 to March 31, 1998

PRESENTATION MATERIALS
FROM
DARPA REVIEW AT CALSTART
APRIL 1, 1998

DARPA Electric and Hybrid Electric Program Review
CALSTART Headquarters
Burbank, California
April 1, 1998

Draft Agenda

Time	**Program Topic**	**Presenting Company**
8:30 – 8:45	Welcoming Remarks	CALSTART
8:45 – 9:~~45~~ 13	Flywheel Shock Testing and Life Cycle Testing	US Flywheel Systems
9:~~15~~ 30 – 10:~~30~~ 15	Mobile Flywheel Power Module and Quick Charge Demonstration	Trinity Flywheel Power
10:15 – 10:30	**Break**	
10:30 – 11:15	Distributed Energy Management System	Delco Electronics
11:15 – 12:00	Phase II Hybrid Electric Bus Program	Foothill Transit District & Gillig Corporation
12:00 – 1:15	**Lunch**	
1:15 – 2:00	Prototype Hybrid Electric Truck	ISE Research
2:00 – 2:45	Heavy-Duty Vehicle Industry Analysis	CALSTART
2:45 – 3:00	**Break**	
3:00 – 4:00	JTEV Related Projects	AeroVironment and Rod Millen Special Vehicles
4:00 – 4:45	Hybrid Electric Vehicle Turbogenerator with Liquid Catalytic Combustor System	Capstone Turbine
4:45 – 5:15	DARPA EHEV Technology Program on Internet	CALSTART
5:15 – 5:45	Wrap-up Discussion	CALSTART/DARPA

3/16/98

DARPA Flywheel Life Cycle Test Program

Jack G. Bitterly

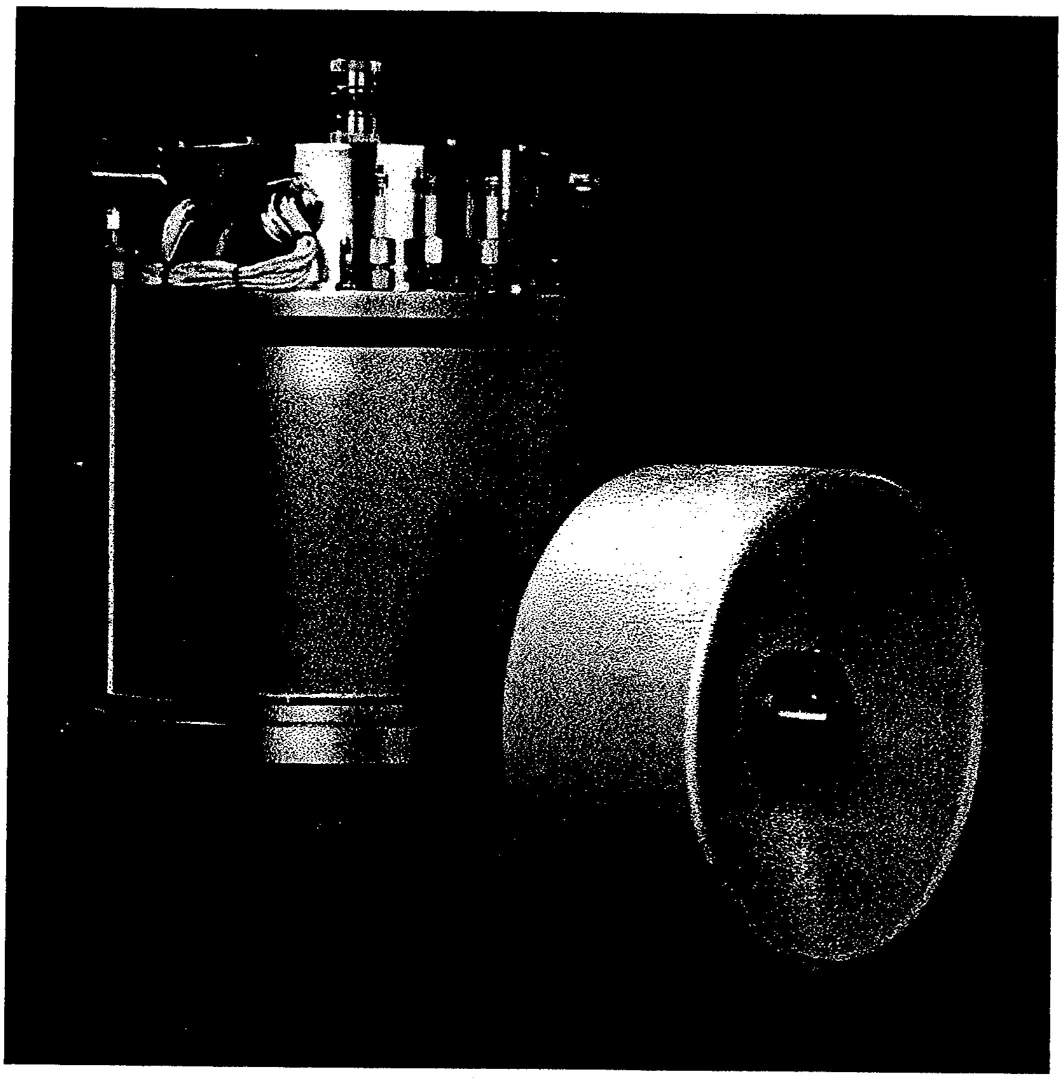
Review Status
April 1, 1998

U.S. Flywheel Systems
...energizing the future.

Flywheel Module Advancements

- Module Hardware Improvements
  - New Internally Designed and Fabricated Magnetic Bearing Actuators — Given-up on Avcon bearings.
  - New Robust Back-Up Bearing
    - 2700 Pound Load Capacity - 200 Pound in Old System
- Bearing Control Improvements
  - New 5 Axes Optical Sensors for Magnetic Bearing Control
    - 50 Times Less Noise than Original Sensors
  - New PWM Power Amplifers for Magnetic Bearing Control
    - Illiminated Saturation Problems
    - Improved Dynamic Bandwidth
  - New DSP Closed Loop Control
- Magnetic Bearing Software Control Developments
  - Developed Robust in-House State Space Control Algorithm
  - Concurrently Working with Dr. Palazollo at TAMU Using Gyroscopic Gain Control

US Flywheel Systems
Magnetic Bearing Flywheel Module and Composite Rotor
DARPA Sponsored Life Cycle Test Program



A magnetically-levitated energy-storage flywheel module (background) and a flywheel rotor (foreground) made by US Flywheel Systems

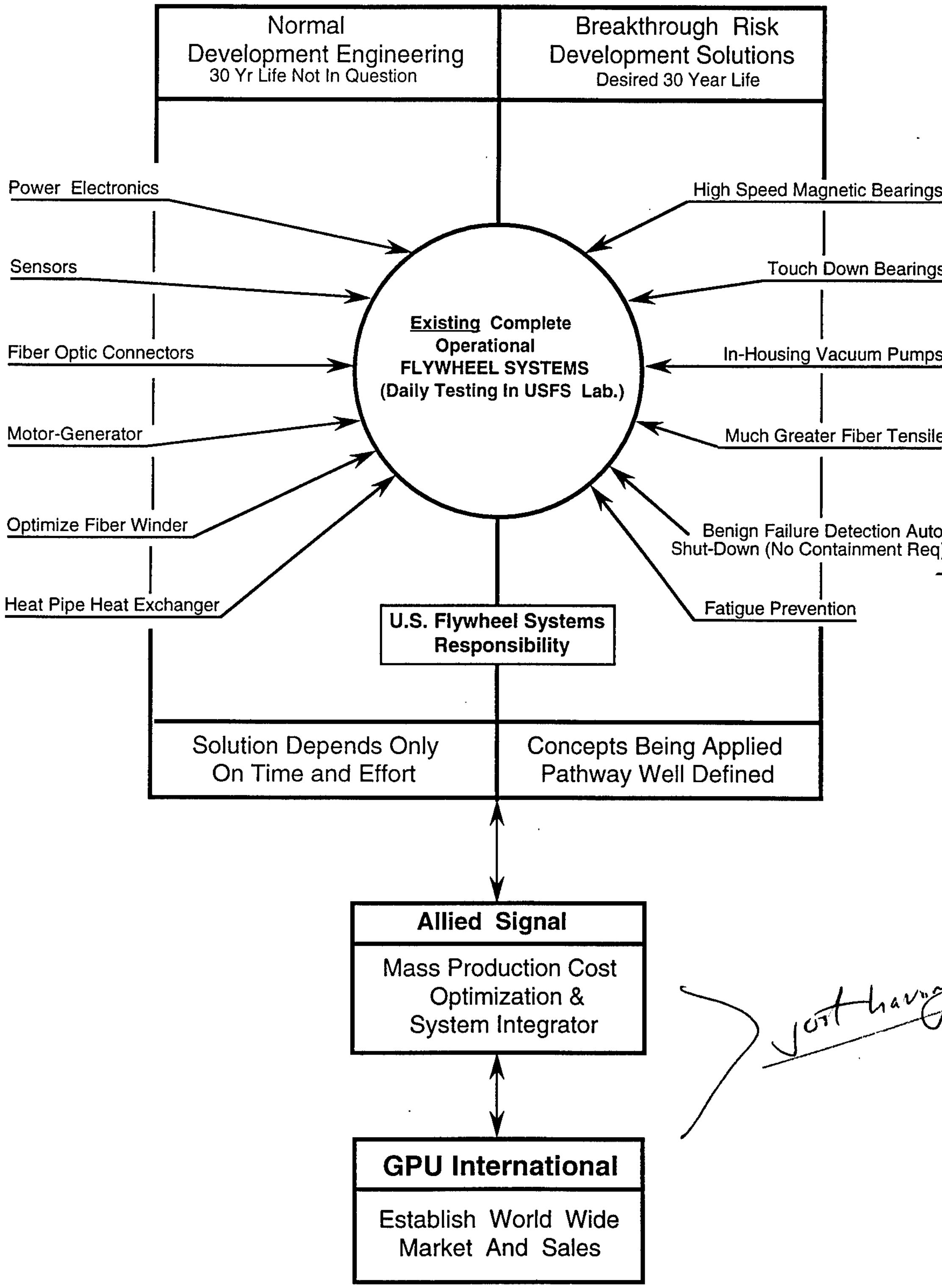
SUMMARY OF U.S. FLYWHEEL SYSTEMS ACTIVITY SINCE NOVEMBER 1993

Type of Flywheel Systems

	Mechanical Bearing			Magnetic Bearing		
No. / Model		Comments/Configuration	Test Highlights	Model	Configuration	Test Highlights
GENERATION	1 st	Horiz. Axis Metal Wheel, Designed To Operate From Solar Panels For Experience In UPS Sun Renuable Energy Complete Power Electronics. Voltage & Frequency Selectable	1. Shipped To NREL Colorado Public Demo. Operated TV, Lights Etc. Direct From 420 W Solar Panels 2. Operated 12 hrs Avg. At **17,325** rpm, Multitude Of Runs Still Functional	USFS #1, #2	1. Company Systems Development, R/D Unit: All Configurations went Thru Many Changes, Tests, Modifications. Was Used To evaluate Our Power Electronics And Sub-Conract Mag Bearings, Which We Canceled In Jan '97; Began Total USFS In-houseDevelopment This Date.	1. Hundreds of Spin Pit In-house Tests Were Performed; Many Of These Were In The Clean Room. The High Speed Rotor Tests Were Conducted @ Balco, Test Devices, Rockwell & Later At USFS. 2. Many Failures, But Never A Supprise Burst, Beginnings Of Proprietary Benign Failure.
	2 nd	Vertical Axis 52 lb Metal Rotor Designed to operate From Solar Or Wall Plug at **42,000** rpm. To Ascertain Predictability Of System Compliance. Completed Life Cycle Test Hardware, Ready For Testing	1. No Failure Of Any Kind, Consistantly Runs @ **42,200** rpm All Day Long. No Detectable Vibration Except From Very Sensitive Instrument. 500 W In-Out. 2. Highest Of Operating Temperatures Is Stator Peaking At 225 deg F.	HI Speed SHAFT	1. This Is A Complete Module, Full Scale But Without A Rotor. Primary A Mag Brg Tool. It also Tests Mgen, Instruments, Sensors, Algorythms, Dynamics & Mag. Bearing Types. These Include Notch Filters (We Now Consider Passe), State Space and we are now initiating neural networks as an advanced system.	1. Progress In Speeds Follow : rpm, Duration 1- 7-98 **15,790** 7 hrs 1- 7-98 **19,500** 2 hrs 1- 8-98 **23,650** 3 hrs 1-17-98 **28,090** 4 hrs 1-17-98 **32,750** 3 hrs 1-18-98 **35,000** 6 hrs 1-19-98 **41,200** 5 hrs 1-21-98 **43,250** 4 hrs
	3.rd	Small, High Performance Fiber	Beginning Design Specs: UPS	DARPA #1	1. 50 lb Graphite Rotor, 18 Kw Mgen High Performance Application 2. Also To Provide Attitude Control Ground Test Evaluation. R/D System 3. Life Cycle Test Development Module	1. Progress In Speeds Follow: rpm, Duration 8-10-97 **15,590** 8 hrs 9-19-97 **19,500** 4 hrs 12-19-97 **11,300** 1 hrs (1st State Space) 12-19-97 **16,500** 4 days (new gyroscopic control law being developed)
				DARPA #2	1. This is a completely rebuilt module With All New USFS Mag Bearings, Actuators Optical Sensors With Temperature Compensation (All 5-Axes), Gyroscopic Compensation with rpm etc.	1. Comprehensive testing will begin mid April '98, and will lead to SVT (Shock & Vibration Article Hardware)

JGB.3.1998

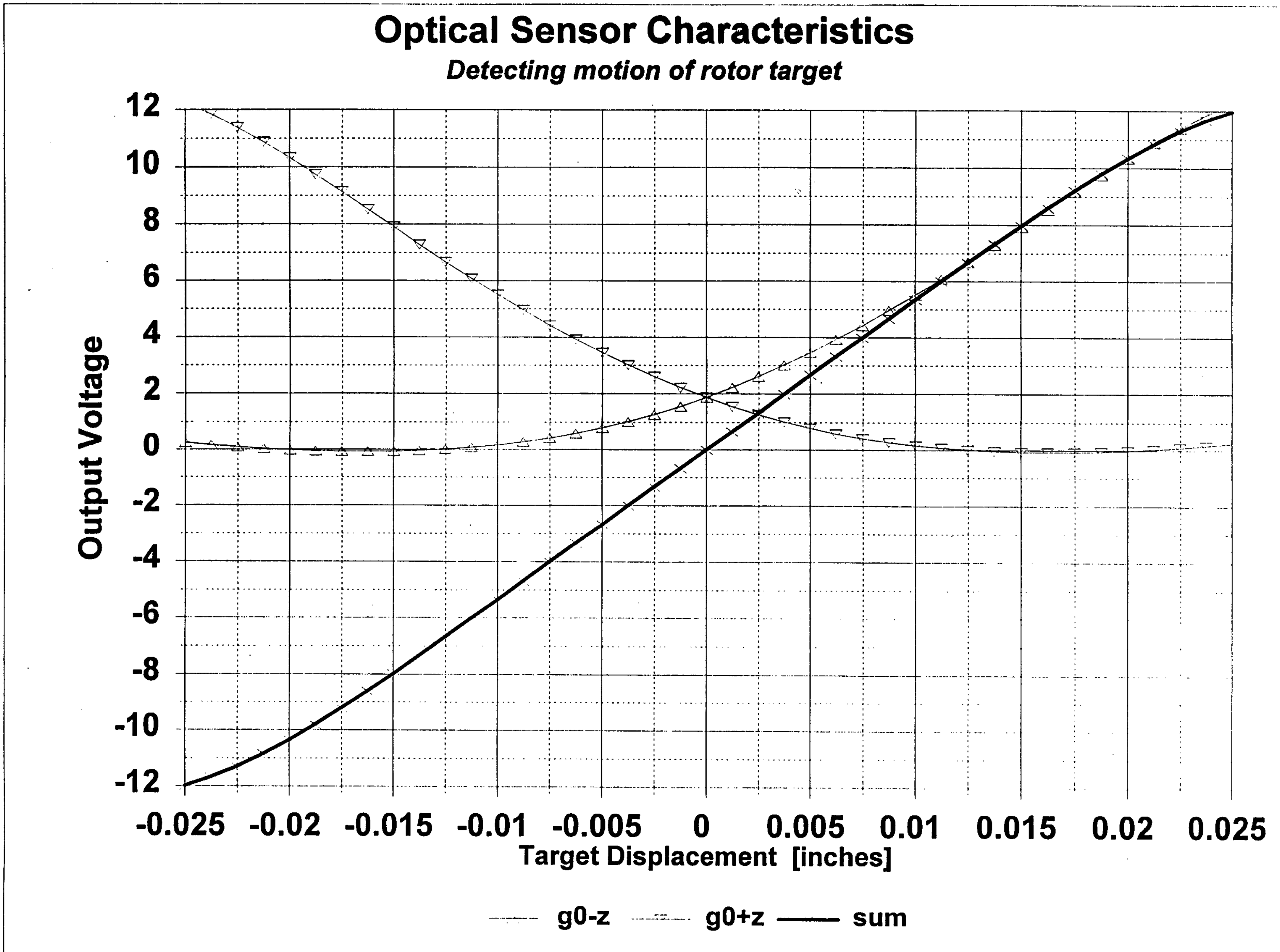
Risk/Reward For Premium Power Flywheel Systems



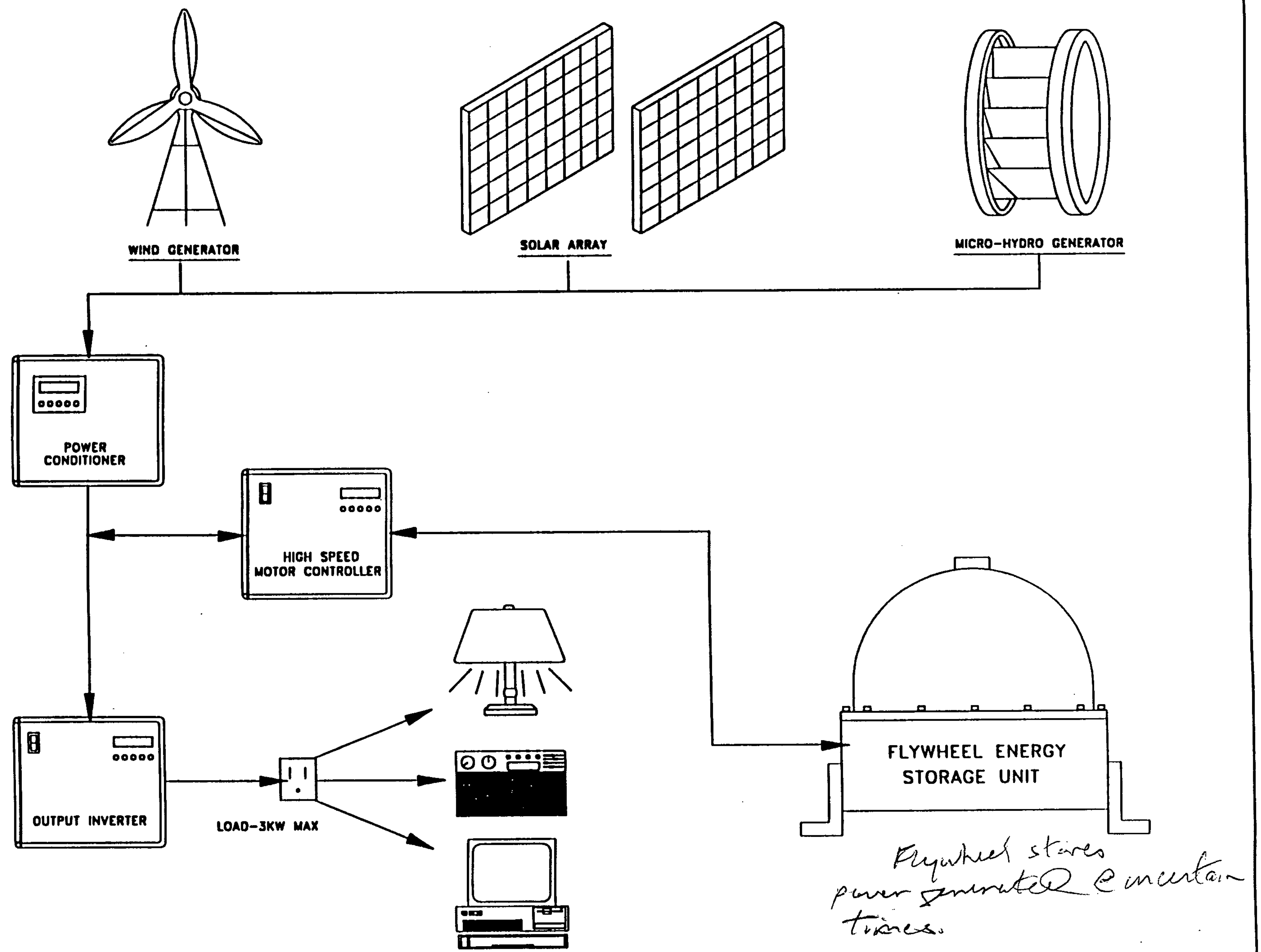
→ should work in all cases but a "major crash"

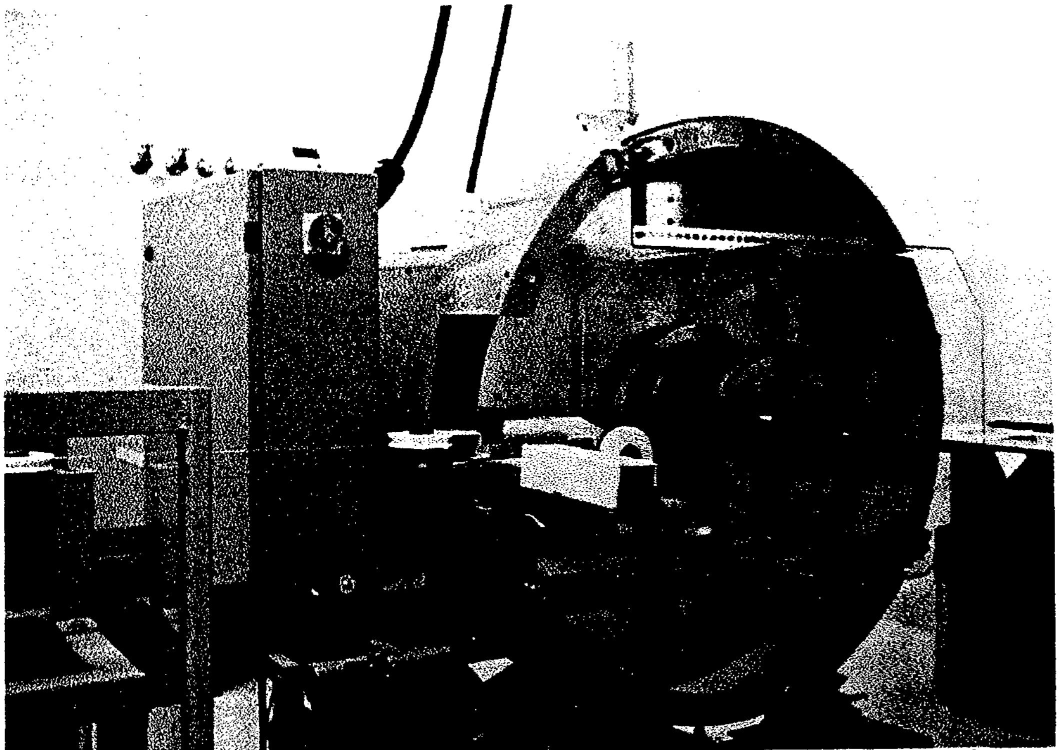
Just having discussion

JGB 3.27.98

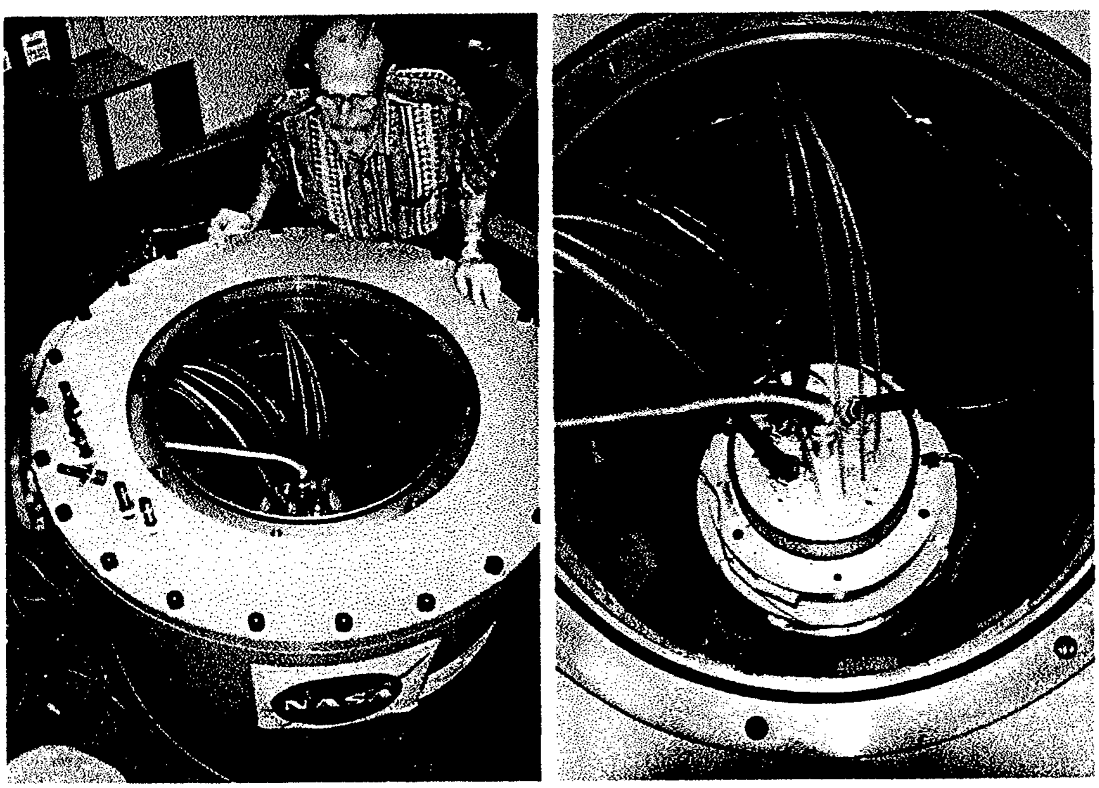

Optical Sensor Characteristics
Detecting motion of rotor target
Output Voltage
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-0.025
-0.02
-0.015
-0.01
-0.005
0
0.005
0.01
0.015
0.02
0.025
Target Displacement [inches]
g0-z
g0+z
sum

U.S. FLYWHEEL SYSTEMS SOLAR ENERGY MANAGEMENT SYSTEM





Precision computer-controlled fiber-composite winding machine at USFS.



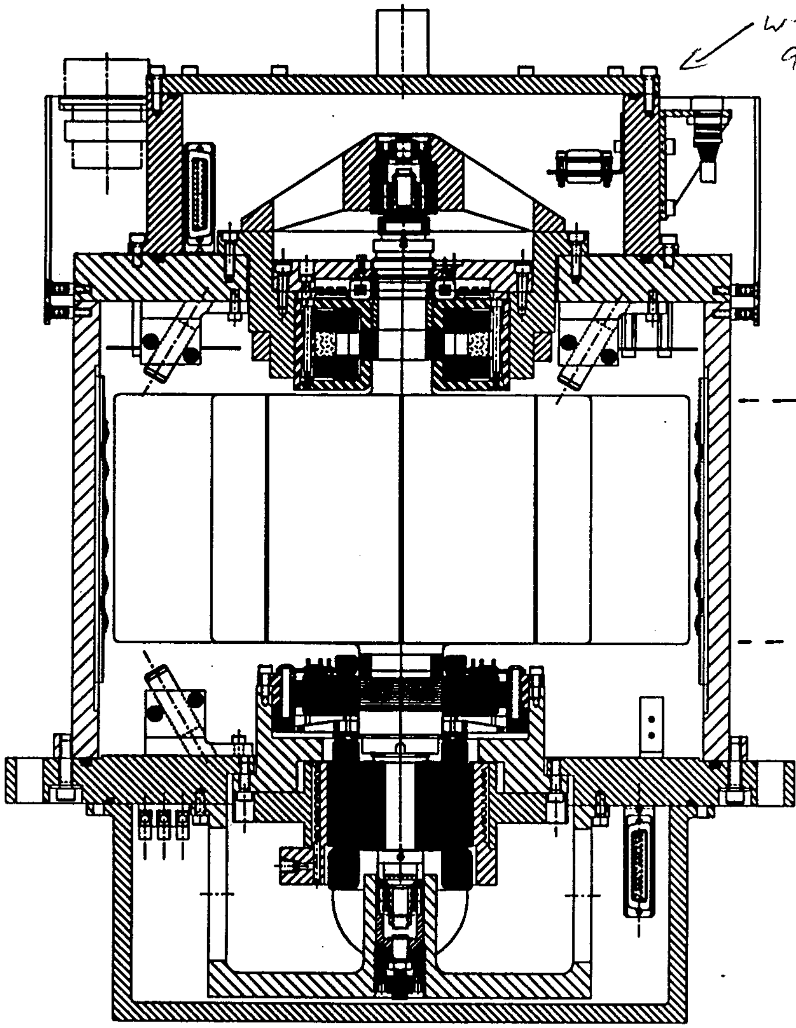
(a) Chamber for spin-testing flywheel rotors at US Flywheel Systems.
(b) Close-up view of an instrumented module within the test chamber.

U.S. Flywheel Systems
. . . energizing the future.®

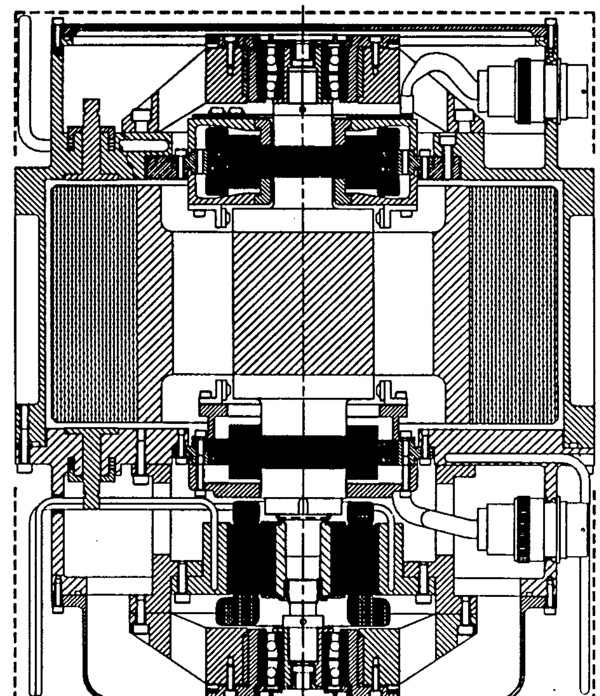
Current and Proposed Flywheel Module

TRW/NASA Flywheel and Proposed ISS Module

TRW/NASA Module
Profile: 13.75" OD x 19.8" L



Proposed ISS Module
Profile: 12" OD x 14.5" L



January 21, 1998.

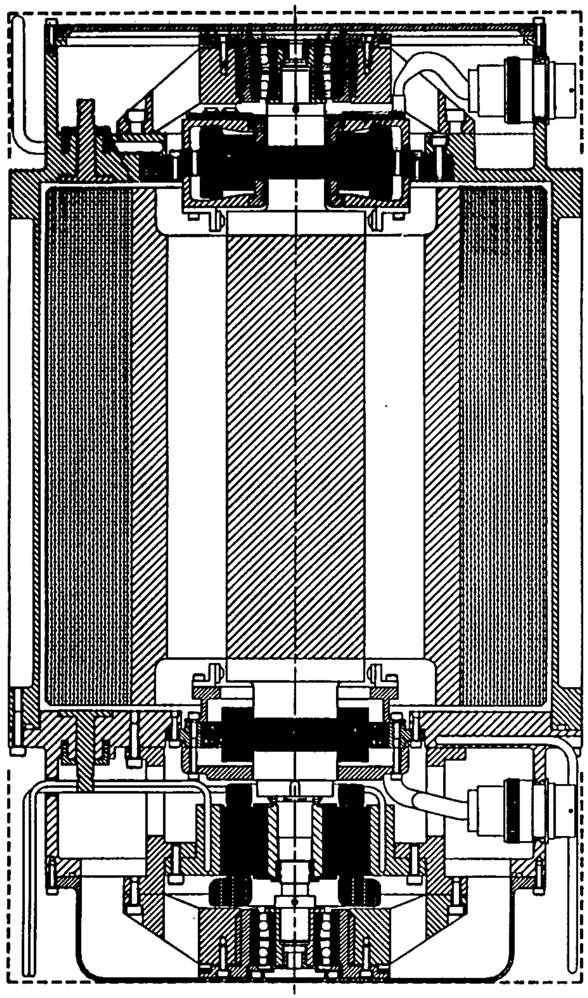
U.S. Flywheel Systems
. . . energizing the future.®

ISS Experiment and Replacement Module

Rotor 6.9" ID x 10.5" OD; ID/OD = 0.657; 60,000 RPM

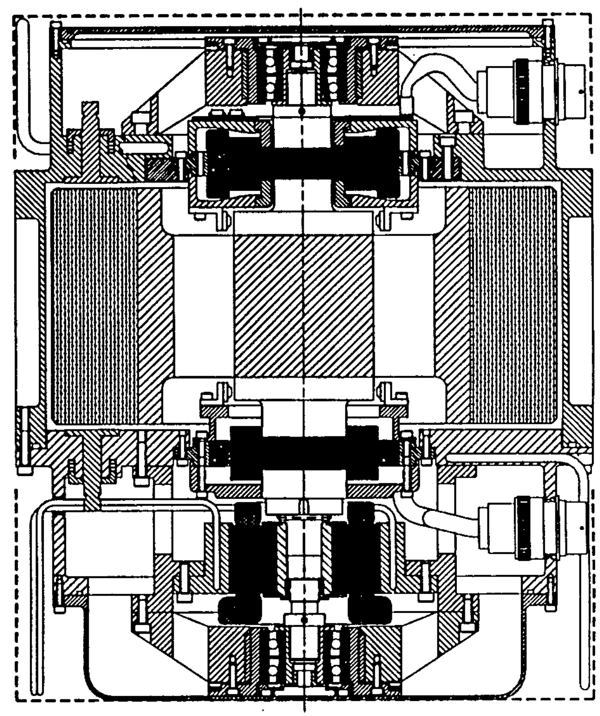
Possible ISS Replacement

Profile: 12" OD x 20.3" L; Rotor: 11" H
Energy: 1250 Whrs; Wt Rotor: 62.0 lbs



Possible ISS Experiment

Profile: 12" OD x 14.3" L; Rotor: 5" H
Energy: 560 Whrs; Wt Rotor: 29.2 lbs



CALSTART

Trinity Flywheel Power

DARPA

Projects

- Rapid Charge System with Flywheel Energy Storage
- Mobile Flywheel Power Module

CALSTART

Rapid Charge System

DARPA

Objectives

- Peak shift: reduce peak power draw during rapid charging
- Mitigate impact of rapid charging on power quality

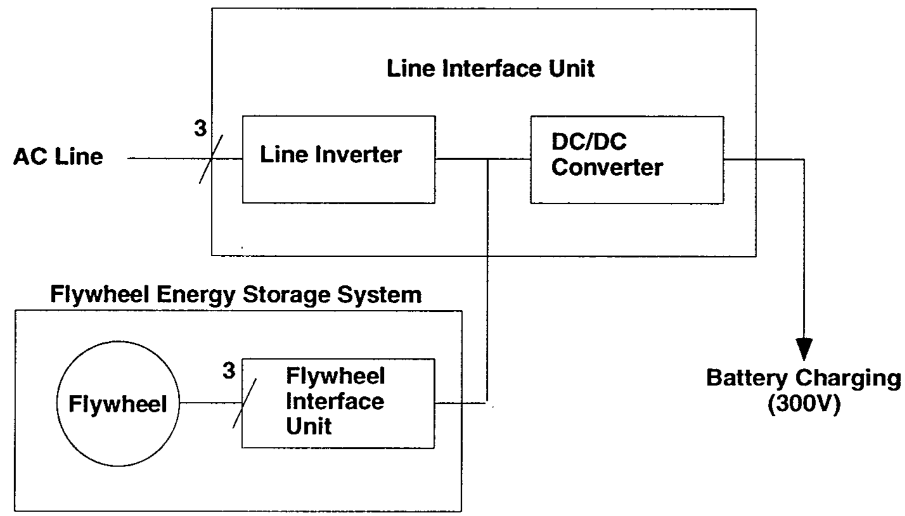
Deliverables

- Initial Plan: Demonstrate flywheel integrated into RCS topology at PG&E Modular Generation Test Facility (MGTF)
- Demonstrate power electronic subsystems
  - Line Interface Unit (LIU)
  - Flywheel Interface Unit (FIU)

CALSTANT

RCS Configuration

DARPA



CALSTART

RCS Team

DARPA

Trinity Flywheel Power
- Flywheel system
- System Integration
- Program Management

Trace Engineering
- ~~Flywheel~~ Line Interface Unit

→ mostly interested in only 250kW inverters for wind & gas turbines. Not as interested in working on other applications.

Montevideo Technology
- Flywheel Interface Unit

Pacific Gas and Electric
- Charging System Testing

RCS Approach

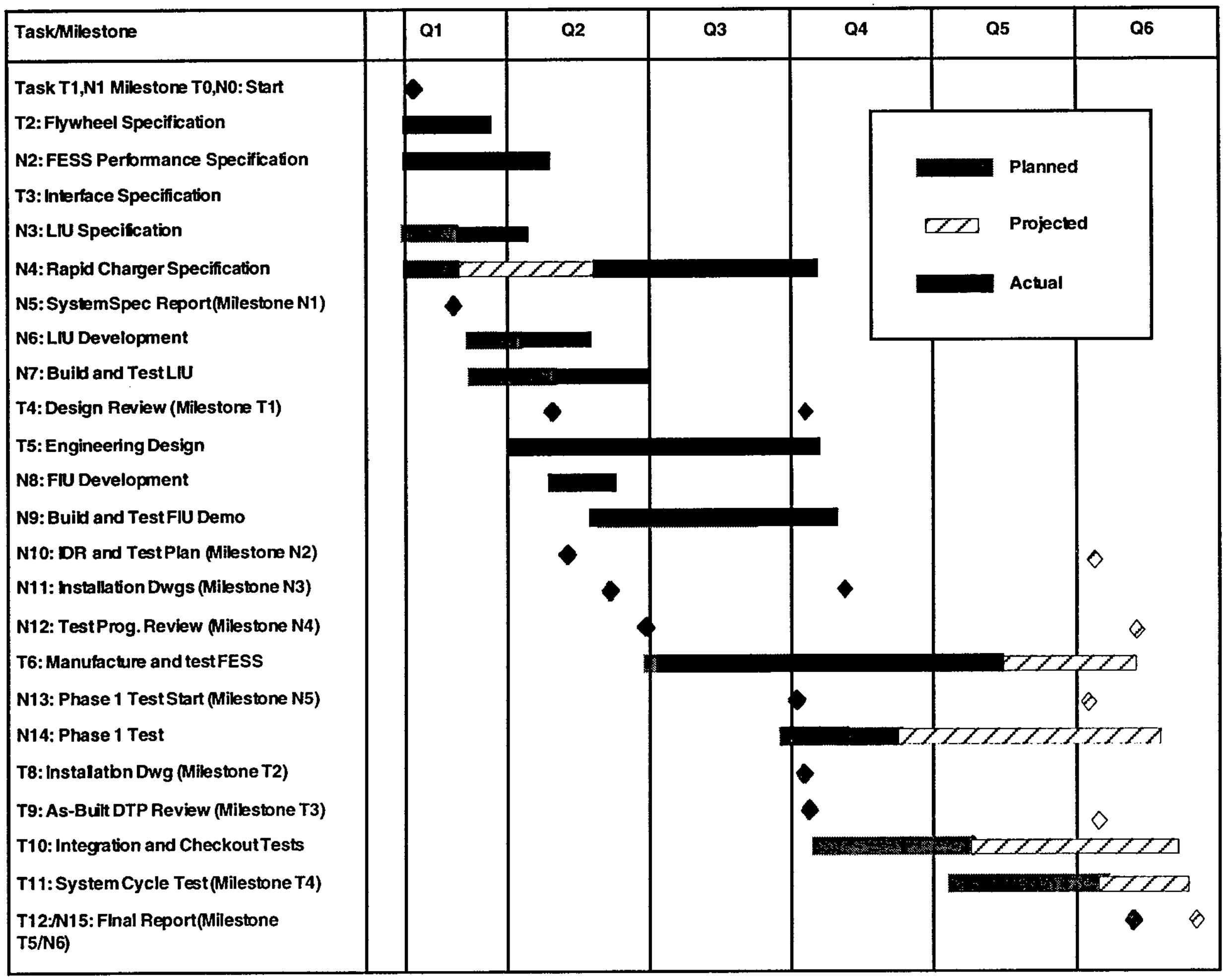
Topology is chosen for performance and greatest commonality with prototype/production intent flywheel motor/generator (FMG) hardware

- Trinity baseline rotor architecture sources and sinks power at 50kW
  - Ongoing programs to demonstrate safety and reliability
  - Derivative FMGs will be evaluated to maximize stored energy while assuring safe operation in field

RCS Schedule

CALSTART

DARPA



TRINITY
FLYWHEEL POWER

TRINITY PROPRIETARY
DAB:April 1, 1998

CALSTART

RCS Status

DARPA

- System manufacturing, assembly, and integration
  - Flywheel Interface Unit installed
  - Demonstrated voltage, speed and current regulation
  - Line Interface Unit acceptance tested 100 kW, <0.5% THD
  - 39,000 RPM, 50 kW, 0.5 kWh flywheel used for system integration
- Marketing
  - Working with new PE partner, jointly marketing system to utilities
- Future direction
  - Testing of full capability planned for 98 second quarter
  - Seeking alternate demonstration site

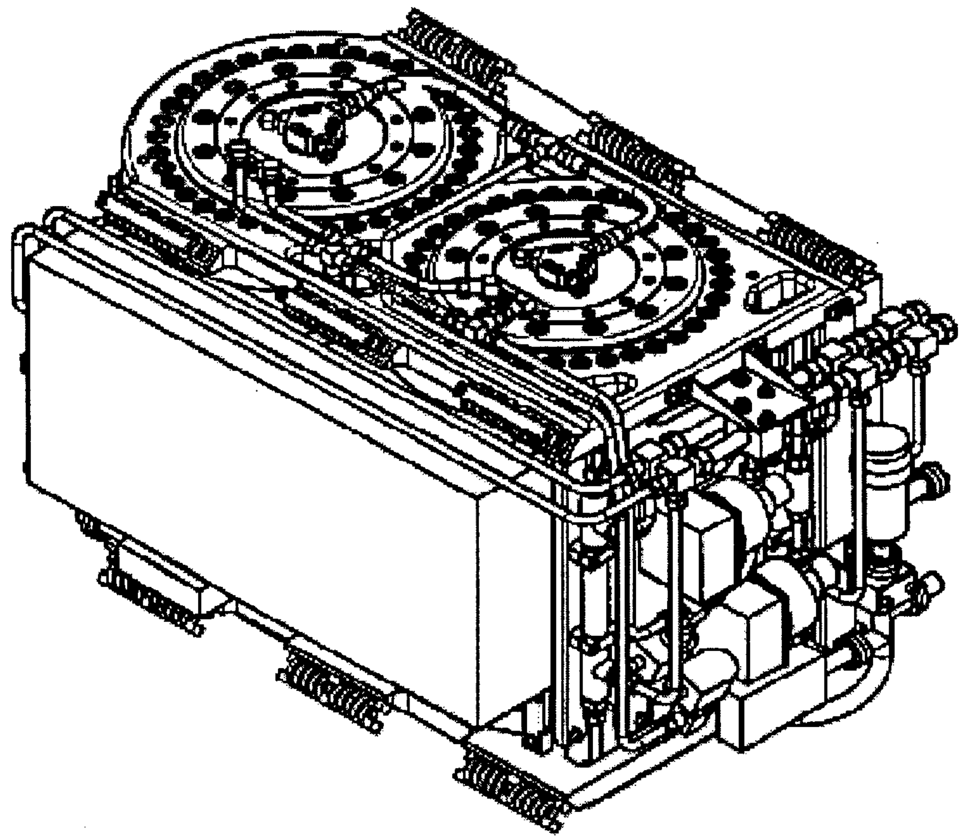
TRINITY FLYWHEEL POWER

TRINITY PROPRIETARY
DAB:April 1, 1998

CALSTART

Mobile Flywheel Power Module

DARPA



TRINITY
FLYWHEEL POWER

TRINITY PROPRIETARY
DAB:April 1, 1998

CALSTART

MFPM Technical Objectives

DARPA

- Single module with two speed-matched, counter-rotating flywheels to cancel net gyroscopic torque
- Total module weight <600 lb
- ✓ Overall dimensions: 24"x24"x36", including flywheels, containment, and power electronics
- Power output: 750 kW for 2-3 seconds, 500 kW for 5-10 seconds, 250 kW for 10-20 seconds.
- Recharge/regen at 100-200 kW.
- Demonstrate performance in high vibration environment such as testing to MIL STD 810E

Land vehicle oriented

CALSTART

MFPM Markets

DARPA

"already heavily marketing this system"

Military

- Pulsed power for weapons systems, hybrid propulsion
- Current/Potential customers
  - Raytheon, LLNL, TACOM

For a mil. customer

Goes Kehl?? Want to do full enviro. test. TACOM help?

Boeing Technical Services will do shaker testing for Trinity

Commercial

- Domestic and foreign hybrid transit buses
- Many manufacturers considering hybrids
  - Similar performance requirements
- Current/Potential customers
  - Hino, Orion

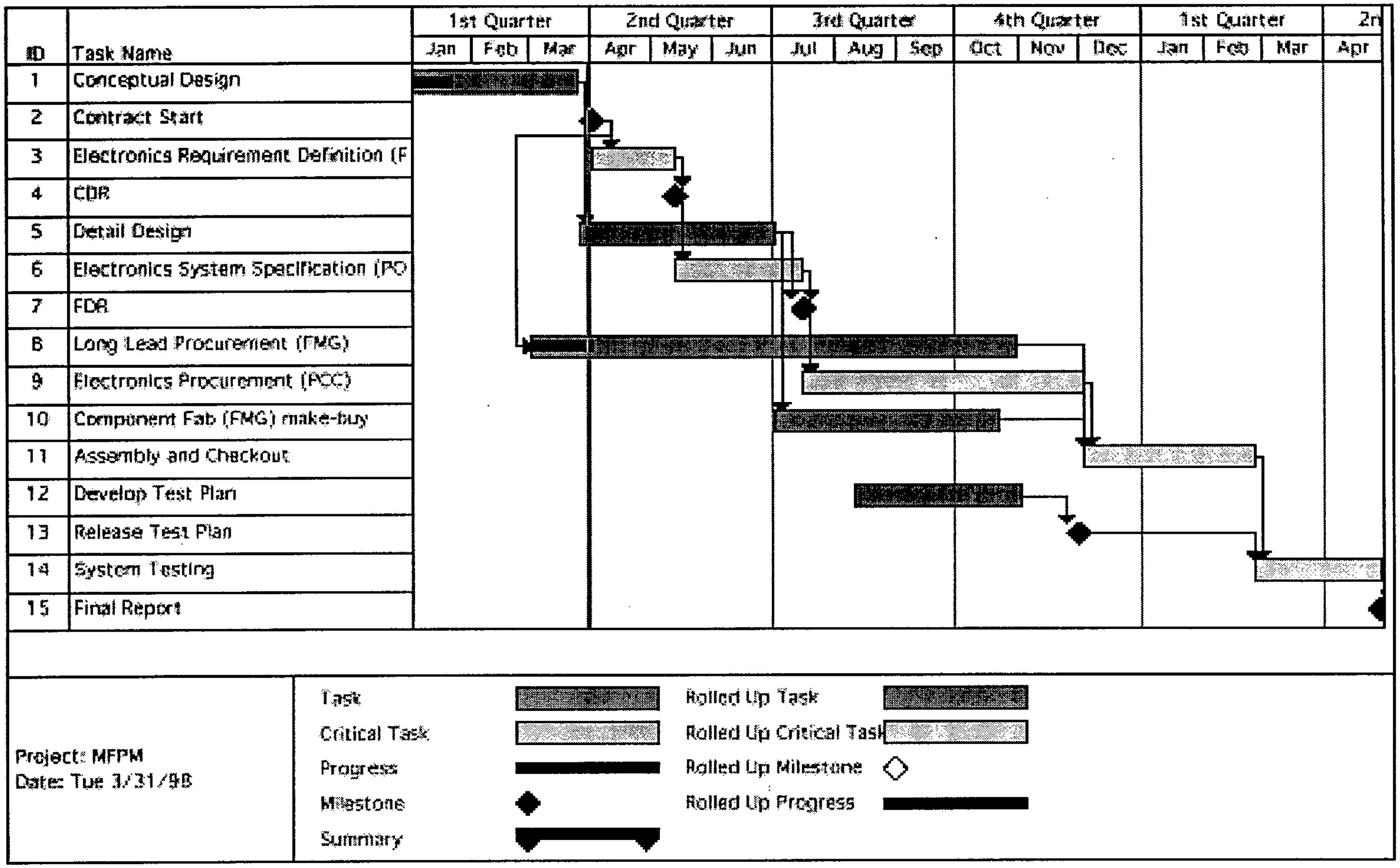
3rd largest truck mfgr. in world.
Been doing hybrid buses for 20 years. 10-15 systems per year
Use flywheels to get rid of black smoke.
MITI ~~upgrading~~ interest in hybrid systems

For Hino, flywheel would replace 4,000 lbs. of batteries. w/containment structure, flywheel system is 600-800 lbs — 1/5 of weight ...

TRINITY
FLYWHEEL POWER

TRINITY PROPRIETARY
DAB:April 1, 1998

MFPM Schedule



TRINITY
FLYWHEEL POWER

ORION BUS INDUSTRIES
ORION®

ORION VI
LOW FLOOR HYBRID-ELECTRIC

SPECIFICATIONS
Orion VI Low Floor Hybrid-Electric

Dimensions

Length	40' - 9.5" (over bumpers)
Width	102"
Height	122" (over roof access doors)
Front Overhang	79" (includes bumper)
Approach Angle	9°
Rear Overhang	100.0" (includes bumper)
Departure Angle	9°
Breakover Angle	10°
Wheel Base	270"
Turning Radius	37' - 6" (over bumpers)
Curb Weight	30,180 lbs.
GVW	44,400 lbs.
Floor Height	15.5" Slopes At Doors To 14.5"

Doors	Slide Glide	
Front	Clear Width 35"	Step Height 14.5"
Centre	Clear Width 43"	Step Height 14.5"
Rear	Clear Width 35"	Step Height 14.5"

Auxiliaries

Power Steering	Hydraulic Pump / 336V Motor
Air Compressor	Driven By 220 V AC Motor

Axles / Suspension

Front	ZF RLE 66, Independent, MacPherson Strut
Capacity	14,550 lbs.
4 - Rear	GE / Dana Spicer, Independent, Teledyne Dble Wishbone
Capacity	7.500 lbs ea. (30,000 lbs. total)

Drive Train	Diesel-Electric
Engine - Diesel	B5.9, 190HP, 4 Cycle, In-Line 6 Cylinder, 142kw max @ 2500 rpm
Generator	Onan, 100 kw DC @ 40°C And 1800 rpm
Wheel Motors, 4 - AC	75 hp, GE - MVEP, 150 lbs-ft Torque, Oil Cooled
Battery Pack	270 Cell Saft NiCad. Capacity 80 Ah. Storage 25 kwh.

Other Features

Tire Size	305/70 Rx22.5, Rated @ 7400 lbs
Brakes	Front - Lucas Air Disc, Rear - S-Cam Air With 16.5 x 5 Drum
Fuel Tank - Diesel	100 US gallons
HVAC (roof mount)	Thermo King R-4, W/R134A, AC 90,000 btu, Heat 95,000 btu
	Orion Front Heater 73,000 btu
Destination Sign	Customer Spec.
Electrical System	Modular 3 kw, 12/24 V Output
Ramp (front entrance)	32" x 44"
Kneeling At Front Door	11" From Ground
Seating	Up to 38
Driver's Seat	Recaro AM 31, B100W USSC 9001ALX

Orion Bus Industries Ltd.
5395 Maingate Drive
Mississauga, Ontario, L4W 1G6
Phone: 905 625-9510
Fax: 905 625-5218

Orion Bus Industries Inc.
Base Road, P.O. Box 449
Oriskany, New York, 13424
Phone: 315 768-8101
Fax: 315 768-3513

Printed in Canada

Distributed Energy Management System (DEMS II)

Jeff Taylor
Steve Ables

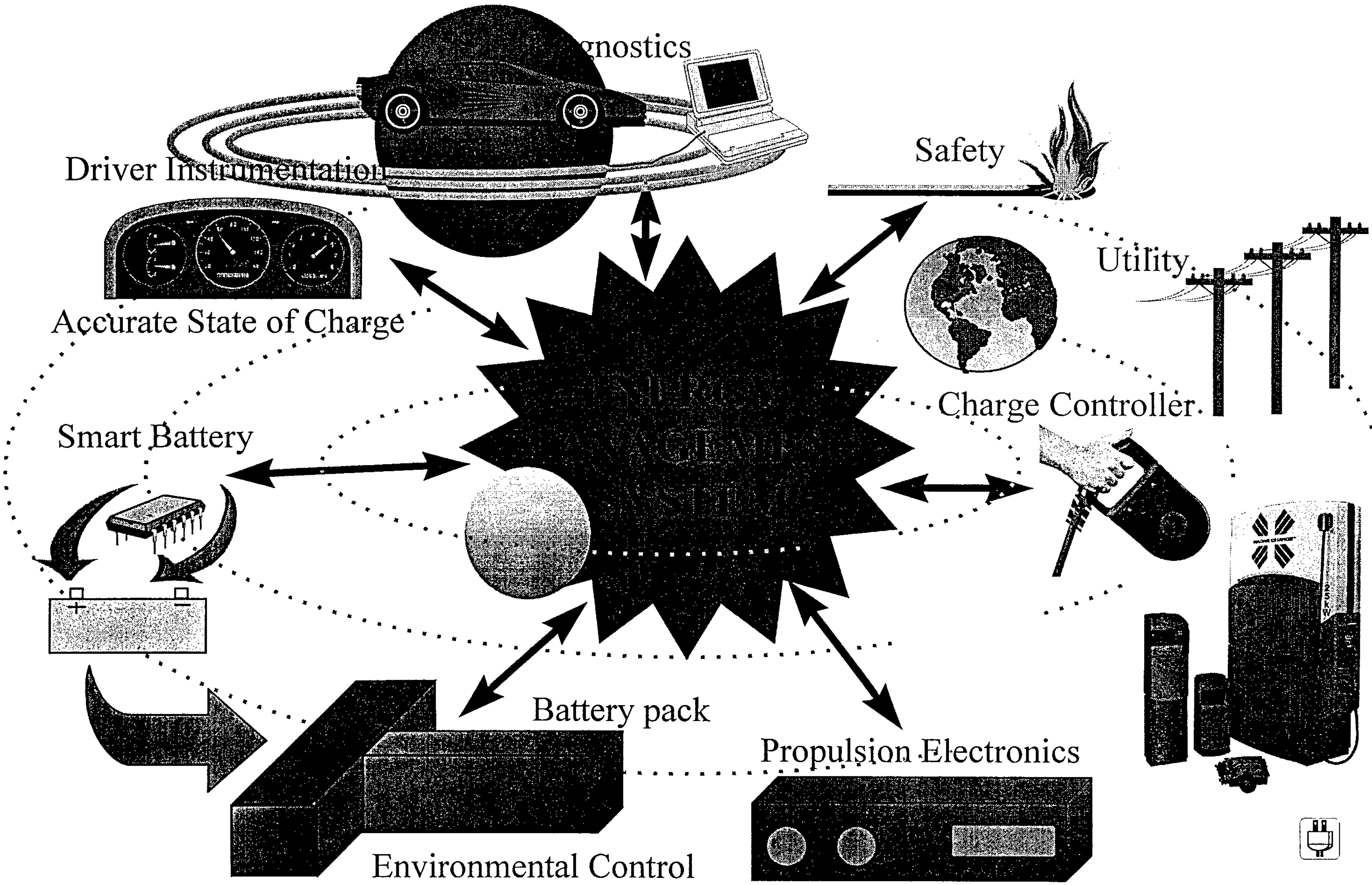
Program Review

April 1, 1998

BY

Raytheon Technical Service Company

Distributed Energy Management System



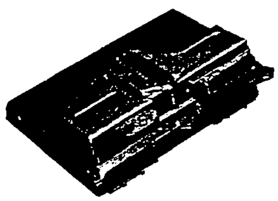
INTRODUCTION

- **RAYTHEON TECHNICAL SERVICES COMPANY**
  - Part of Raytheon Systems Company
  - Extensive working relationship with GMATV
    - Remanufacturing/repair contract services
    - Magnecharge system
    - Energy management
  - Current projects - DEMS I
  - Facilities
    - Torrance, CA; Indianapolis, IN; Richmond, VA
  - Available products
    - Charge controllers, charge ports , conversion boxes, test equipment

RAYTHEON

E V COMPONENTS

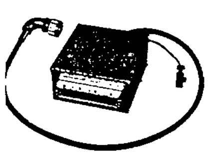
CC200 Charge Controller



The **CC200** is a microprocessor based electric vehicle battery charger controller and energy management system that **can be used on Conductive and Inductive charging systems.** It uses an enbedded system architecture to house battery charging and energy management algorithms in user configurable memory. During the charging process the CC200 continuously monitors the state of the batteries and controls the inductive charger output level via the SAE Class 2 Communication Interface (protocol J1850). The CC200 has many safety features which will protect the user, vehicle and battery pack. CC200 has the capability of reading traction battery pack voltage with 12 bit resolution, reading charge / discharge current using fine (0-+100A) or course (0-+2500A) measurement channels, and monitoring, with a resolution of 8 bits, the auxiliary battery voltage. Developer's software package allows the controller to be program to be customized to your application. Additional features:

- Telemetry (DEMs) Interface (RS232)
- 2 Pulse Width Modulated outputs
- 7 Isolated Discrete inputs
- 1 Pre-charge input
- 8 bit Aux. Battery sense
- Isolated 12 bit Pack current
- 1 Frequency Measurement inputs
- 9 Temperture inputs
- 12 bit DAC output(-5 to +5 vdc)
- Isolated 12 bit Pack voltage sense
- 2 High side switches
- 1 SPDT Relay and Isolation detect circuit

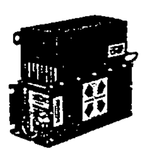
MagneCharge 6.6 kW AC Inductive Charge



Designed as part of the MagneCharge system , the CP 7100 and CP7150 Inductive AC Charge ports were created to provide Vehicle Manufactures, Vehicle Integrator's and Fleet Users with a means to utilize the new Inductive battery chargers that General Motors designed to charge the EV1 and EV S-10 electric vehicles..

- Inductive coupling used to transfer power (50 V to 430V @22 A max and 6.6 kW max).
- FCC certified and UL listed
- No Metal contacts between the charger and the vehicle

MagneCharge - CV7200 Conversion Box



The CV7200 Conversion box connects to the CP7100 and CP7150 Inductive Charge Ports to convert the AC magnetic flux to filtered DC voltage for the vehicle's traction battery pack.

Distributed Energy Management System

DEMS BATTERY MODULE AVAILABLE Early 1998

The DEMS system consists a central controller (CC200) and DEMs battery modules. Each battery module is capable of monitoring two 12 volt battery modules or cells. The DEMs battery module monitors voltage (0-16 VDC) and temperature (-40C -85C) and has a built-in bypass circuit (0 - 1 A) for battery EQUALIZATION. Each DEMs module communicates with the central controller through an opically isolated data link.

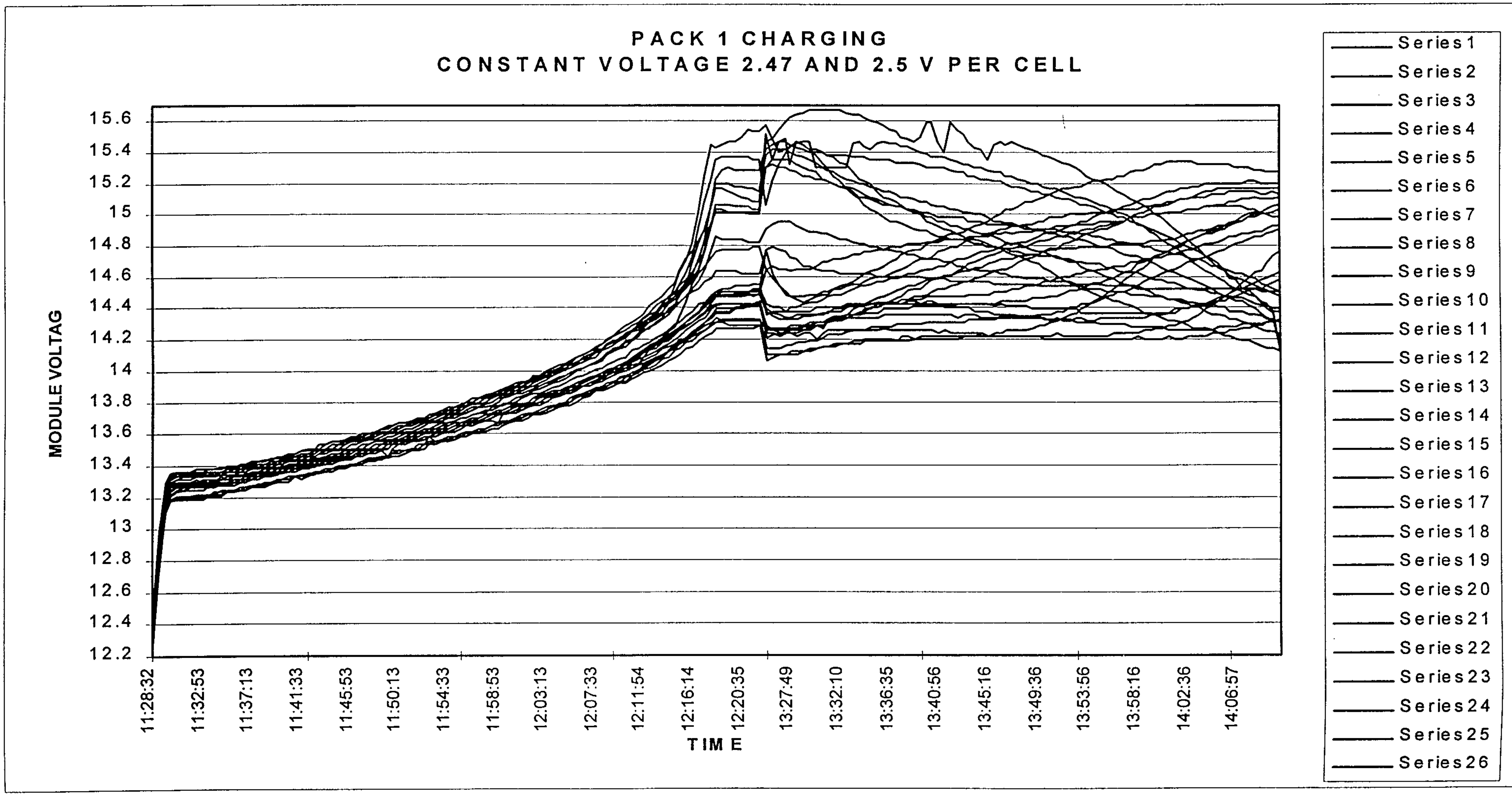
R a y t h e o n -

TO ORDER OR REQUEST INFORMATION CALL
Fax: 317-291-1801 Tel: 317-290-4026
Raytheon 6075 Lakeside Dr, Indianapolis, IN 46278. USA

THE PROBLEM

- **Battery modules at different states of charge (SOC), and temperature can shorten driving range and battery life.**
  - Inherent imbalances in the battery leads to
    - Lower capacity batteries being OVERCHARGED which causes excessive gassing and dries out the battery
    - Higher capacity batteries being UNDERCHARGED, which leads to sulfation build-up.
  - Temperature disparity, between battery modules, leads to improper compensation (overcharging and undercharging modules)
- **Compounded by multiple strings (buses)**
- **High Cost (solution cost vs cost of batteries)**

THE PROBLEM



PACK 1 CHARGING
CONSTANT VOLTAGE 2.47 AND 2.5 V PER CELL
MODULE VOLTAG
15.6
15.4
15.2
15
14.8
14.6
14.4
14.2
14
13.8
13.6
13.4
13.2
13
12.8
12.6
12.4
12.2
11:28:32
11:32:53
11:37:13
11:41:33
11:45:53
11:50:13
11:54:33
11:58:53
12:03:13
12:07:33
12:11:54
12:16:14
12:20:35
13:27:49
13:32:10
13:36:35
13:40:56
13:45:16
13:49:36
13:53:56
13:58:16
14:02:36
14:06:57
TIME
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8
Series9
Series10
Series11
Series12
Series13
Series14
Series15
Series16
Series17
Series18
Series19
Series20
Series21
Series22
Series23
Series24
Series25
Series26

THE SOLUTION

According to Danny Gorske — this system offers communication from battery pack to controller.
In lab have tested w/ a variety of batteries.

- **PROVIDE A UNIVERSAL, *COST EFFICIENT* ENERGY MANAGEMENT SYSTEM THAT CAN:**
  - MONITOR INDIVIDUAL BATTERY MODULE OR CELL VOLTAGES AND TEMPERATURES
  - COMPENSATE FOR BATTERY CAPACITY VARIATIONS THROUGH ACTIVE EQUALIZATION (CHARGE OR DISCHARGE).
  - EXPAND TO MULTI- BATTERY PACK CONFIGURATIONS, SUCH AS THOSE FOUND IN BUS, HYBRID, AND MILITARY PROGRAMS
  - ADAPT TO VARIOUS BATTERY CHEMISTRIES
  - PROVIDE OTHER FUNCTIONAL CAPABILITIES, SUCH AS ISOLATION DETECTION AND THERMAL CONTROL TO REDUCE COSTS IN OTHER AREAS.

Now technology focused on EVs only

PROGRESS

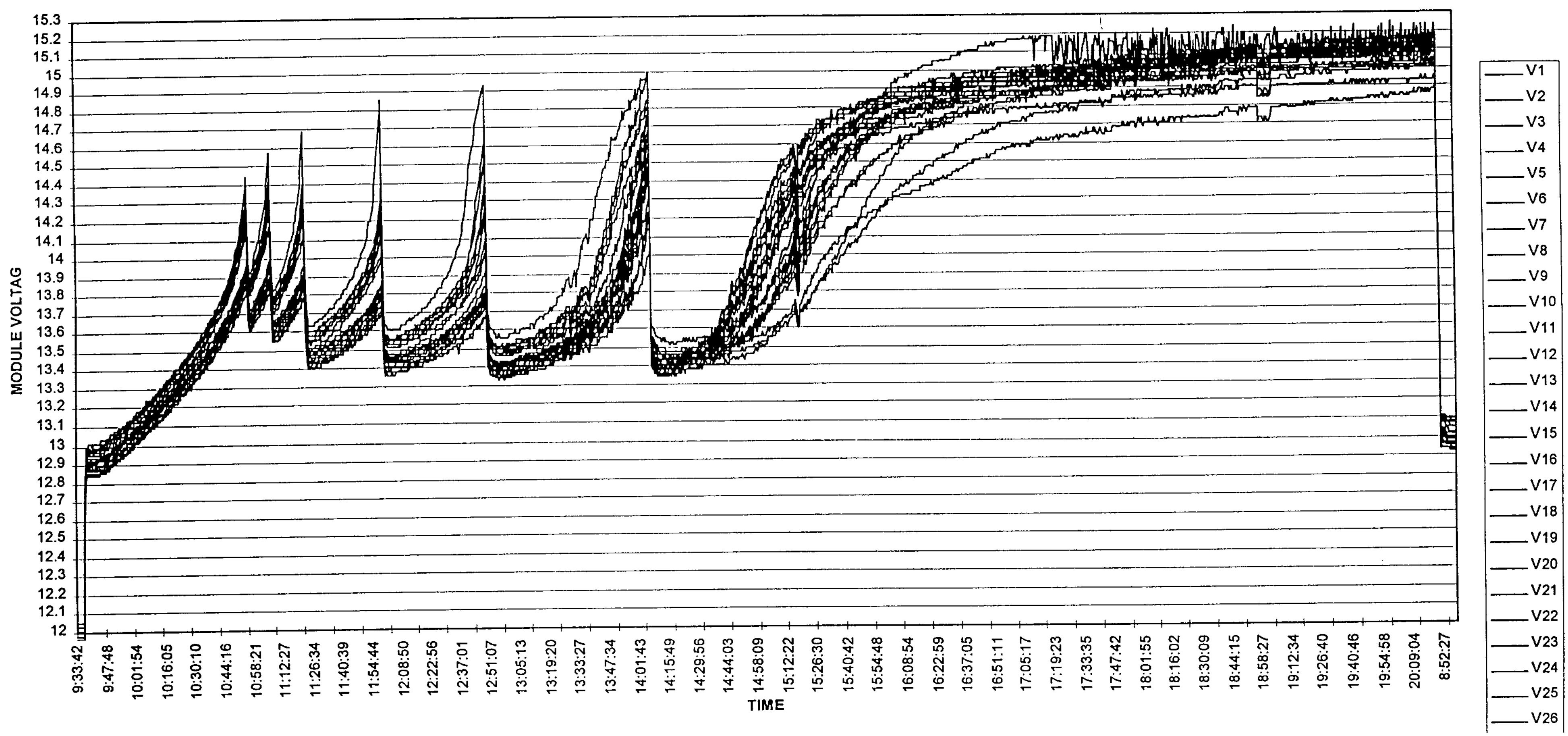
Can work w/ a conductive or inductive system.

DEMS I PROGRAM (AIDED BY FY 96 DARPA FUNDING)

- **Development of Magnecharge on-vehicle components with a multi-charge controller system for heavy duty bus applications**
  - Used to develop charging techniques for multiple strings in parallel
  - Increase in range on both buses.
- **Development of hardware and software for charging control of individual batteries**
  - DEMS Central Controller (CC200)
  - 13- Prototype DEMS Battery Modules
  - Data indications
    - Lower capacity batteries no longer being overcharged
    - Higher capacity batteries no longer being undercharged
    - Battery Pack temperature variations accounted for by temperature compensating individual batteries

PROGRESS

PACK 1 CHARGING PROFILE



PROBLEMS ENCOUNTERED

Connect APRI w/ Raytheon?

- **REDESIGN EFFORT FOR THE BATTERY MODULES**
  - COMMUNICATION THROUGHPUT PROBLEM WITH THE CC200
  - ONGOING PROCESS
- **COST OF PARTS AND ASSEMBLY DUE TO LOW QUANTITIES.**

TODAY	TOMORROW
$20-40/battery(cost to us)	$5-10/battery(cost to us)
multiple components	single component
small market	large market

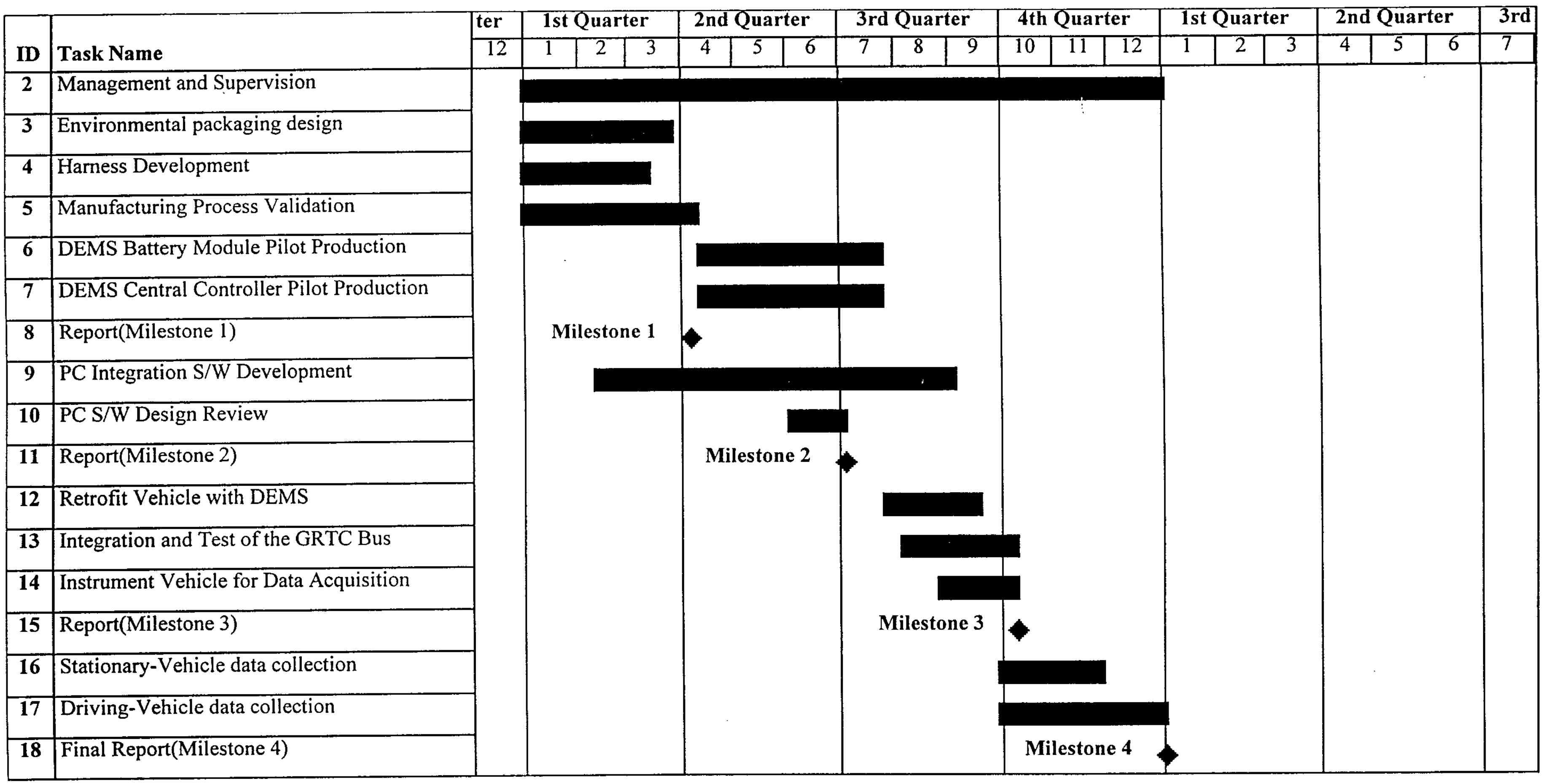
- **VEHICLE PROBLEMS UNRELATED TO ENERGY MANAGEMENT(such as braking systems)**

COMMERCIALIZATION PLAN

DEMS II — ~~M~~ Productization focus. Make it smaller & lower cost. Can't be reviewed on strict comm. plan — needs to show technical risk. Do in-vehicle testing.

- **LOOK FOR COST SHARE FUNDING**
  - * CALSTAT
  - * DARPA
  - * AQMD
  - * RAYTHEON
- **WORK WITH OTHER SUPPLIERS & DARPA CONTRACTS**
  - SEMICONDUCTOR(MOTOROLA, ETC)
  - BATTERY SUPPLIERS(OVONICS, HAWKER,GNB, SAFT, DELPHI)
- **PRODUCTIZE THE BATTERY MODULES**
  - MECHANICAL/ENVIRONMENTAL PACKAGING
    - THROUGH HOLE VS SURFACE MOUNT
  - SELL COMPONENTS TO BUS MANUFACTURERS, CONVERSION HOUSES, BATTERY MANUFACTURERS, AND OEMS
- **DEMONSTRATE THE VALUE OF THE TECHNOLOGY**
  - ON VEHICLE TESTS

SCHEDULE


ID
Task Name
ter
1st Quarter
2nd Quarter
3rd Quarter
4th Quarter
1st Quarter
2nd Quarter
3rd
12
1
2
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4
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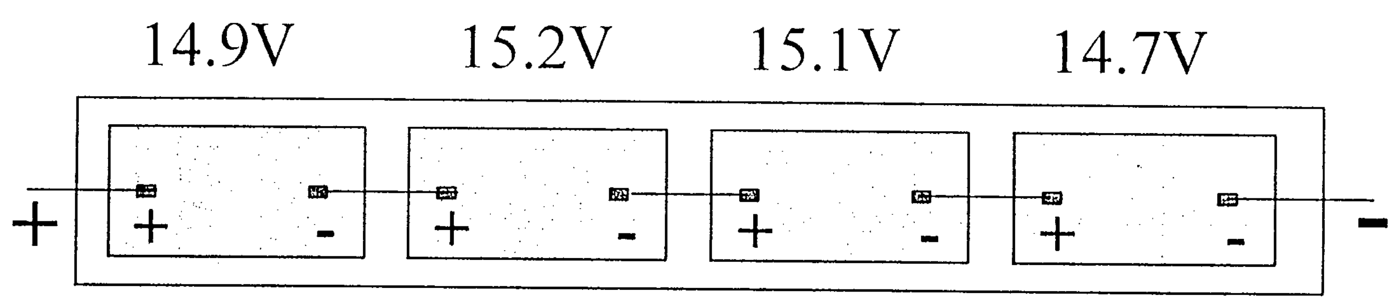
7
2 Management and Supervision
3 Environmental packaging design
4 Harness Development
5 Manufacturing Process Validation
6 DEMS Battery Module Pilot Production
7 DEMS Central Controller Pilot Production
8 Report(Milestone 1)
9 PC Integration S/W Development
10 PC S/W Design Review
11 Report(Milestone 2)
12 Retrofit Vehicle with DEMS
13 Integration and Test of the GRTC Bus
14 Instrument Vehicle for Data Acquisition
15 Report(Milestone 3)
16 Stationary-Vehicle data collection
17 Driving-Vehicle data collection
18 Final Report(Milestone 4)
Milestone 1
Milestone 2
Milestone 3
Milestone 4

DEMS

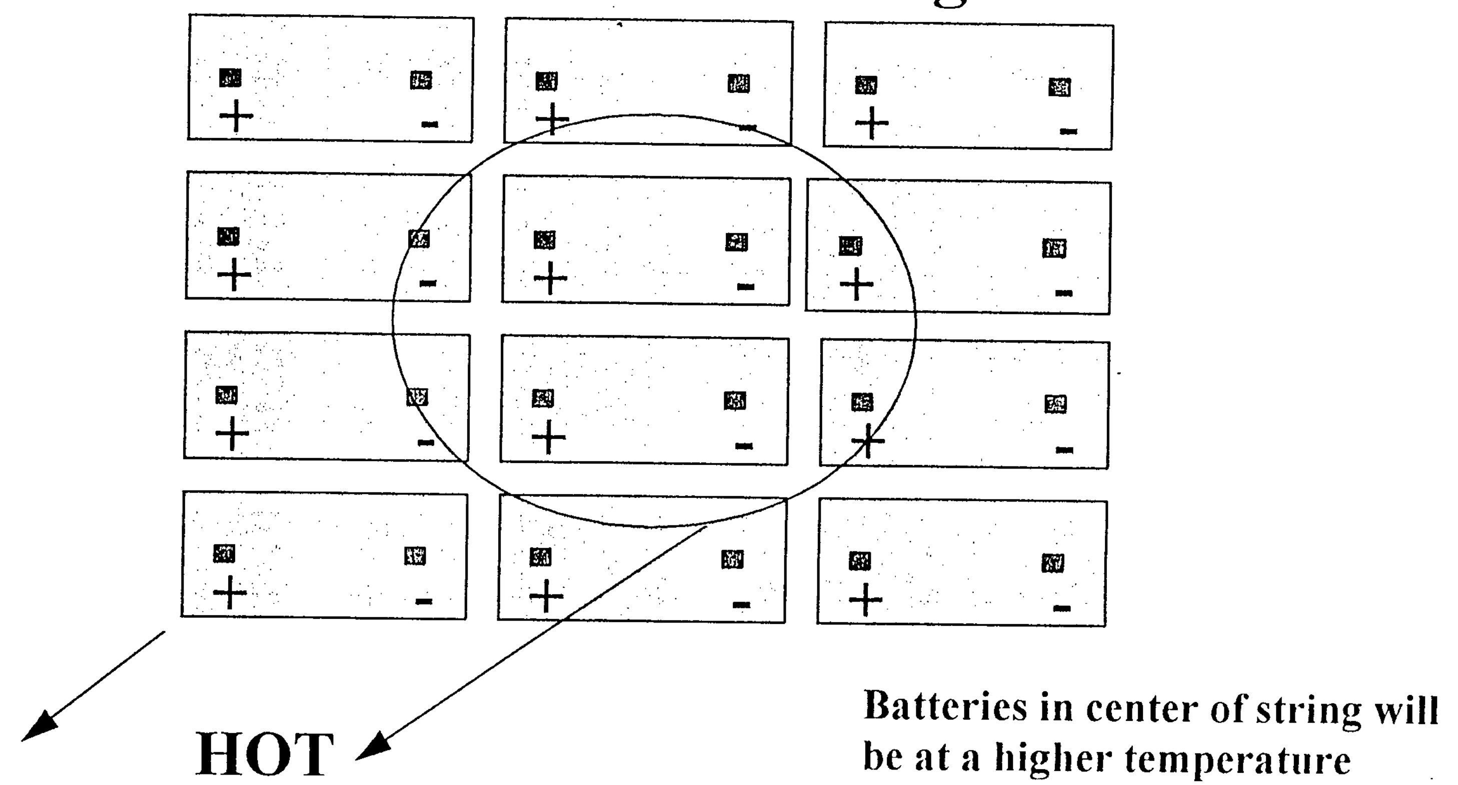
Batteries in a string will charge and discharge at different rates due to slight variations in the manufacturing process and location in the pack.



Battery life is reduced if it is not properly charged - affects the capacity of the entire battery pack.

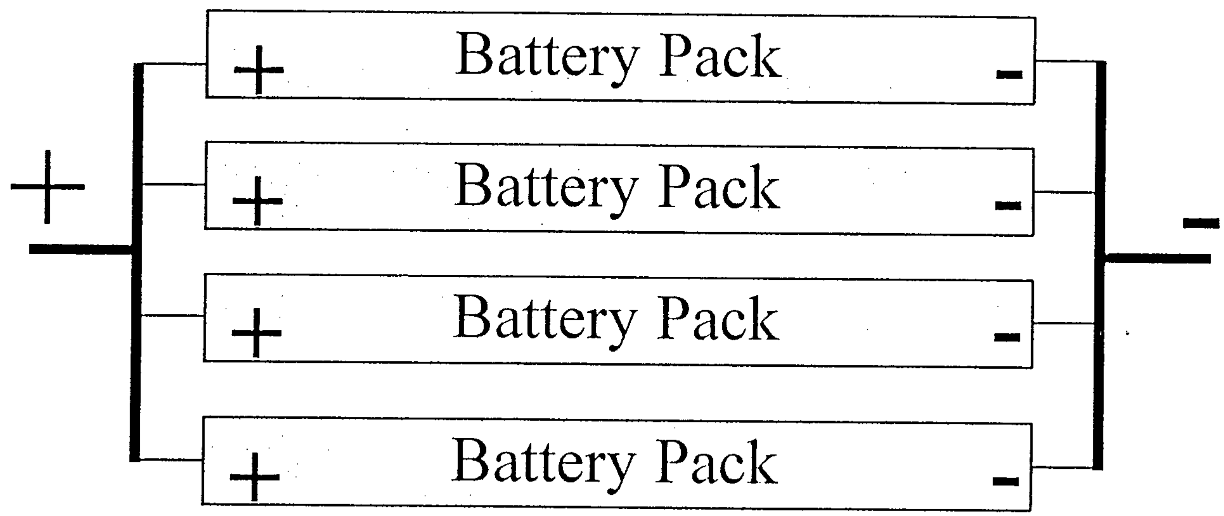
DEMS

Batteries of low capacity and higher temperature will reach full charge first and will gas, while the high capacity batteries remain undercharged.



DEMS

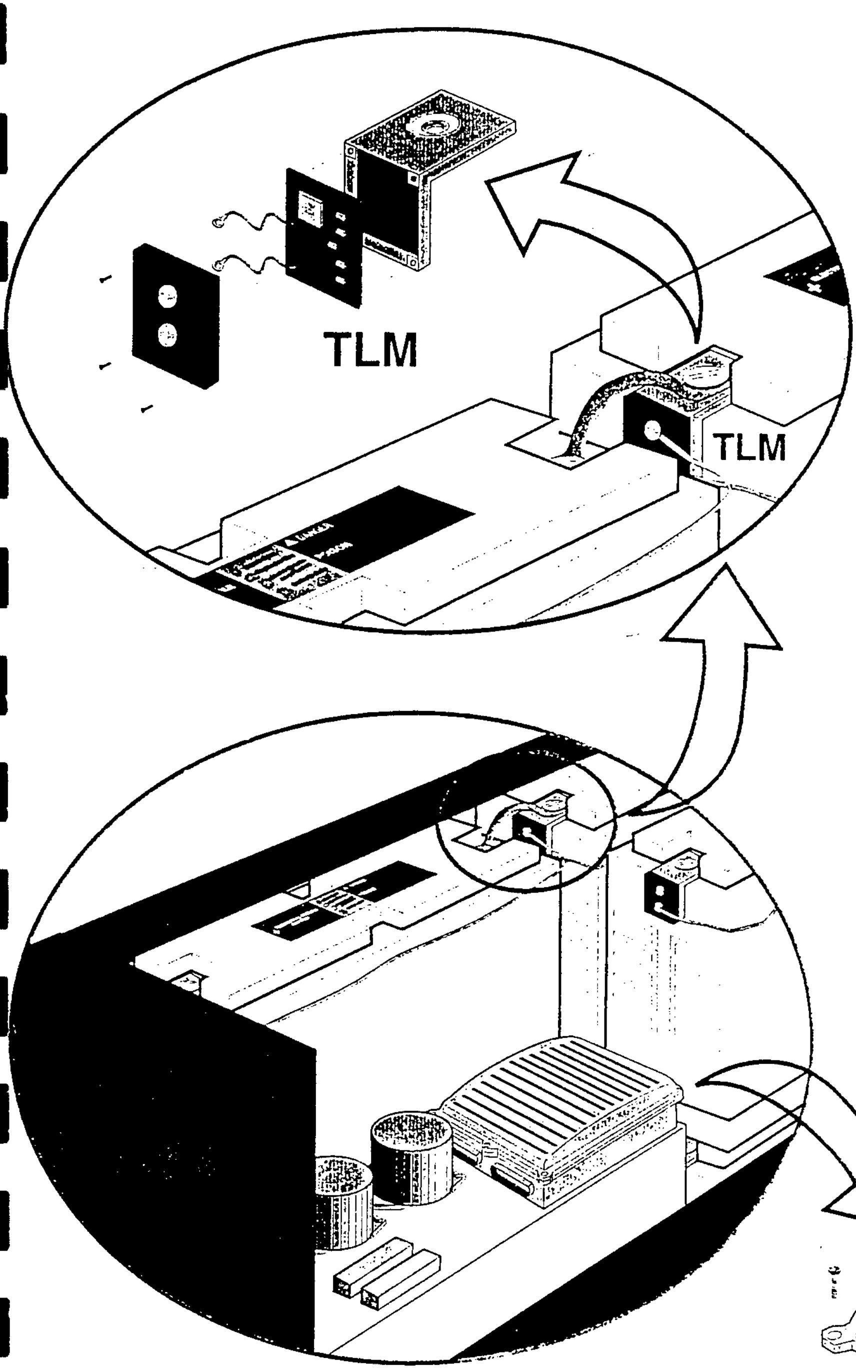
Large variations in capacity exist between battery packs connected in parallel . 27 batteries x 4

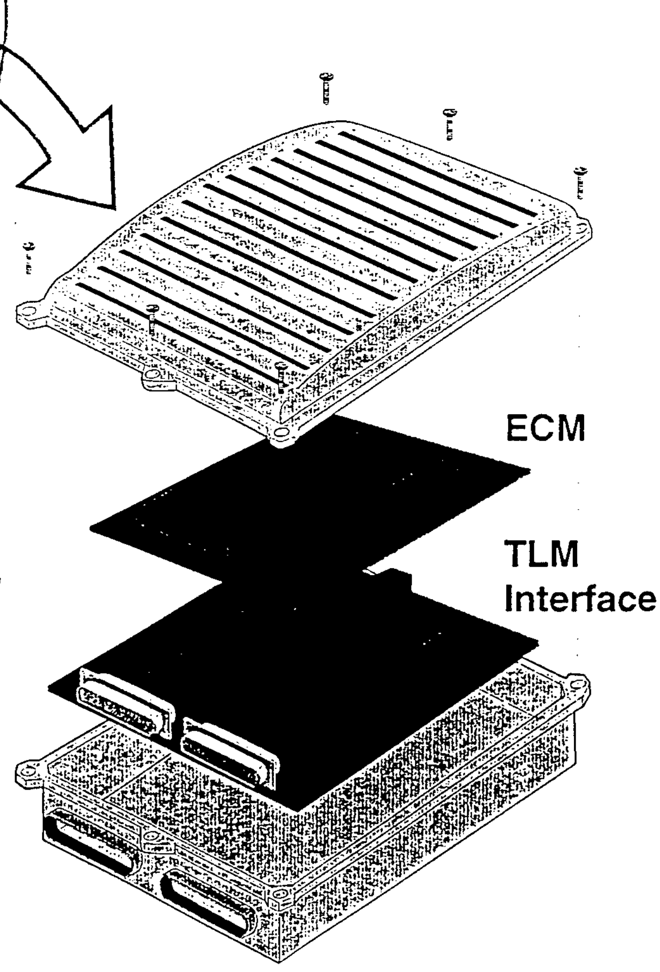


Monitoring and controlling the packs at the module level;the packs will all receive the optimum charge.

Distributed Energy Management System (DEMS)

(TLM+ Controller)





Delco Propulsion Systems

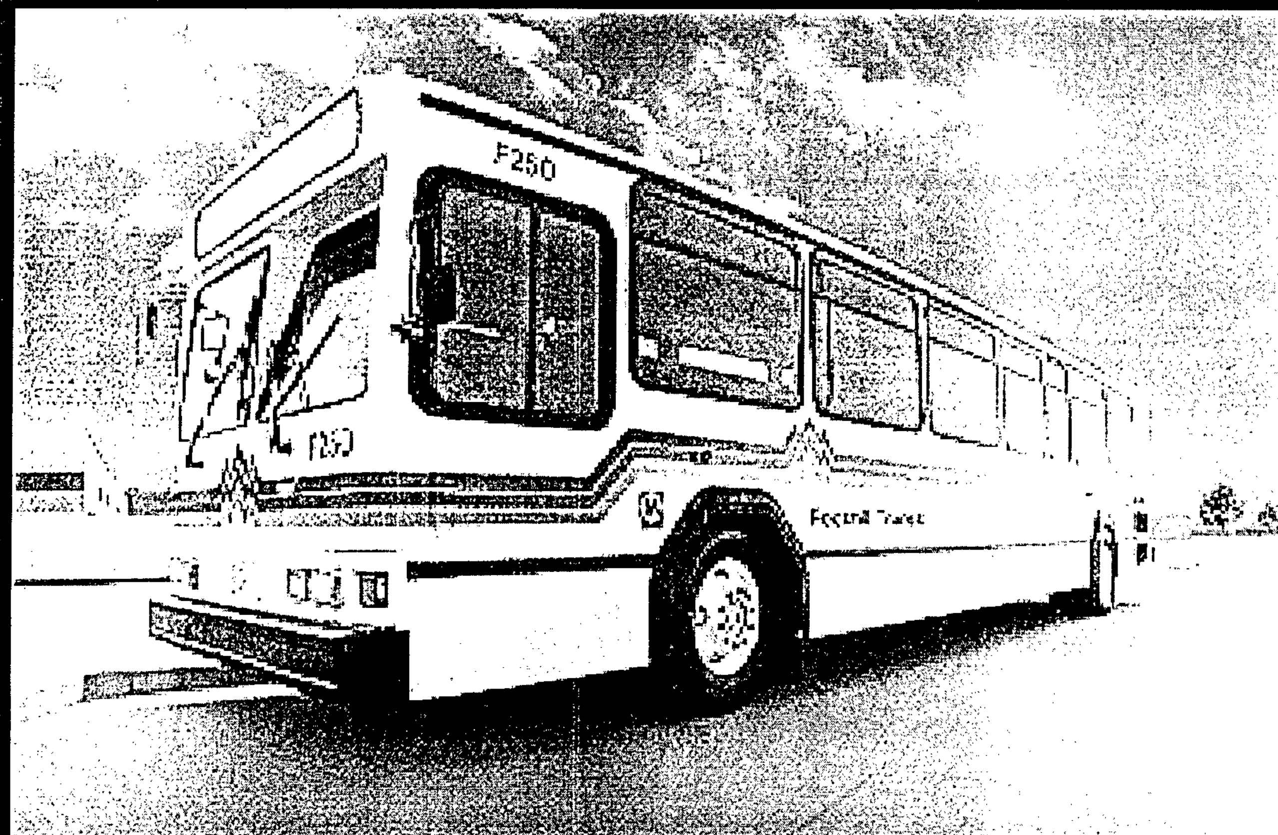
CALSTART

Hybrid Electric Transit Bus

DARPA

Foothill Transit and the Gillig Corporation

Foothill Transit



Overview of Foothill Transit

- Primary Provider of Transit Service to the Pomona and San Gabriel Valleys
- Operates a fleet of 259 Transit Coaches
  - 212 buses in peak service
- Operate 560,000 Vehicle Service Hours in FY98
- Will serve 16.2 million customers during FY98
- The San Gabriel and Pomona Valleys have some of the poorest air quality in the nation

Overall Project Phases

- *Pre-project*--Gillig to develop one prototype hybrid-electric CNG bus for Golden Gate Transit
- *Phase One* --Conversion of a standard diesel bus to an electric-hybrid CNG bus
- *Phase Two*--Monitoring of the performance of the hybrid-bus
- *Phase Three*--Development of a low-floor hybrid-bus
- *Phase Four*--Replacement of Foothill Transit's entire fleet at a rate of 33 buses per year

Project Description

- Develop and demonstrate low-cost hybrid-electric bus (on standard high-floor chassis)
- Equip with a CNG fueled internal combustion auxiliary power unit (APU)
- Determine commercialization potential
- Field test bus for one year in regular transit service

(*See hand-out for bus specifications*)

Hybrid Bus Milestones

Tentative Schedule

MILESTONE	ORIGINAL	REVISED
• Finalize Design	NOV 97	JULY 98
• Order Major Components	JAN 98	OCT 98
• Design Major Systems	FEB 98	DEC 98
• Build Vehicle Shell	FEB 98	JAN 99
• FINISH ASSEMBLY	APR 98	MAR 99
• Manufacturer Testing	MAY 98	MAR 99
• Emissions Testing	JUNE 98	MAR 99
• FIELD TESTING (12 Months)	JULY 99	APR 00

Project Status, Progress

- Steps underway
  - Deliver and test Golden Gate Transit prototype
  - Finalize design parameters
  - Discuss controls with Siemens
  - Begin major component selection
  - Electrical system design
- Next quarter
  - Begin procurement of components
  - Continue electrical system designs
  - Begin design of engine installation - mechanical
    - » Cooling system, engine mounting, inverter

Problems Encountered

- Gillig delays, problems, building Golden Gate Transit prototype
  - Prototype delivery 1 year late (yesterday - March 31, 1998)
  - Problems with CNG component
    - » tanks recalled
    - » fittings not compatible
    - » supplier went bankrupt; Gillig had to take responsibility
    - » extra heat generation
    - » limited space for tanks under the bus
  - Problems with batteries (selected by contractor)
  - "Basic" bus with low power, "backyard generator"
    - » Cannot control some components electronically

Problems Encountered (cont'd)

- Gillig needs extra time to design electronic controls
  - Must develop sensors, actuators to control throttle
  - Engine output for electric generation
  - Hybrid controller ("black box") communicates with engine
  - Controller must control throttle output, monitor engine performance
  - Looking for more compatible batteries to handle extra heat
- CNG engines do not have sophisticated electronic controls like diesel
  - Cummins CNG engine throttle controls are mechanical
  - No other bus manufacturer has developed this technology
  - Mechanical controls only provide limited capabilities

Issue - CNG vs. Diesel

- Diesel APU will speed delivery by 3 to 6 months
- No other manufacturer has started on hybrid-CNG
- Gillig will not build CNG in commercial production
- Manufacturers say there may be little commercial demand for hybrid-CNG
- CNG capital and operating costs, safety issues
- Hybrid-diesel emissions will meet 2004 standards, current CNG levels

Orion. New Flyer. & Neoplan ⇒ checked w/them + they concur

Issue - CNG vs. Diesel *(cont'd)*

- Hybrid-diesel emissions comparable to CNG
  - "Advanced Diesel" already meets 2004 standards
  - Hybrid engine runs at idle most of time (most efficient)
    - » Need smaller engine, mainly for power generation
    - » best fuel economy (33% to 50% better mpg)
    - » lowest emissions (correspond to fuel economy)

EMISSIONS COMPARISONS (very preliminary data)

	EPA	Diesel	CNG	Hybrid-Diesel	Hybrid-CNG
NOx	4.0	4.0	2.0	under 2.0	?? under 2.0
PM	.05	.05	.02	.02	?? under .02

Orion first put buses on road but MTA.

Other Issues

- Foothill Transit reviewing decisions
  - Need to order replacement buses this year
  - Average delivery times 1 1/2 to 2 years
  - Committed to clean air technology
- No contract with CALSTART for project
  - Staff changes at Foothill Transit
  - Revising project schedule and budget
  - Is project to test hybrid technology, or hybrid-CNG?

MAY 1997

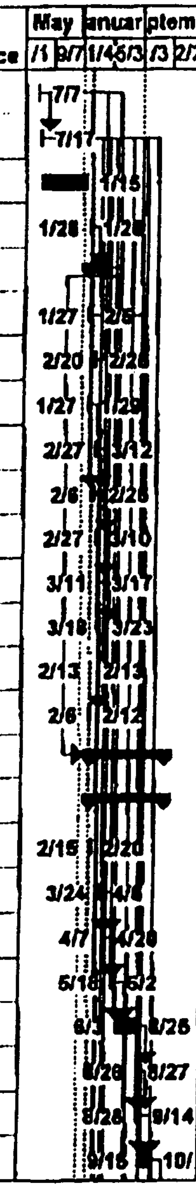
FOOTHILL/GILLIG HYBRID ELECTRIC BUS

Vehicle:	Gillig Phantom Transit Bus
Size:	40' x 102" (Extra width required to accommodate APU)
Seating:	41 with 2 wheelchair positions
GVWR:	39,500 lbs.
General:	Built as closely to Foothill specifications as possible with this drive configuration.
Drive System:	Hybrid electric propulsion system, using a rear mounted CNG fueled internal combustion Auxiliary Power Unit (APU) as a range extender. The APU drives a DC generator which, through inverters, feeds dual AC drive motors. These motors are connected to the drive axle through a combining/reducing gearbox. An underfloor mounted battery pack is used as a load leveler and energy storage device, while a resistor bank dissipates any excess energy.
APU:	Cummins 4B based, converted to CNG. Approx. 175 HP.
Fuel:	CNG, 5 tanks 1,415 cu. ft. Each at 3,000 psi.
Generator:	125 KW, 320V DC
Drive Motor:	Siemens Dual water cooled AC induction motors, with IGBT controllers. Total output 210 KW and 600 NM torque.
Batteries:	Electrosource Horizon bi-polar lead-acid battery, quantity 30. 500 amps. max. current at 30 seconds, 85 amp. hr. at C3 rate, 360 nominal volts, 240 watts/kg.
Brakes:	Regenerative braking of drive motors supplements the standard service brakes. Excess energy dissipated through a resistor bank.
HVAC:	ThermoKing low-energy system with R-134A refrigerant.
Lift:	Lift-U wheelchair lift in front door.
Suspension:	Standard air spring, axles, wheels and tires.
Safety:	- Integrated ground fault detection. - 48 Volt battery groups with standard electrolyte. - Integrated fire suppression system with dual optical spectrum sensors covering the engine compartment, fuel tanks and battery areas.

BM 5/97

FOOTHILL/GILLIG HYBRID ELECTRIC BUS

ID	Task Name	Duration	Start	Finish	% Complet	Resource I	Predece
1	GILLIG MEETING TO FINALIZE DESIGN PARAMETERS	3d	Thu 7/3/97	Mon 7/7/97	50%		
2	MEETING TO DISCUSS CONTROL W/ SIEMENS	3d	Tue 7/15/97	Thu 7/17/97	50%		1
3	Testing and data collection of Golden Gate Hybrid	10d	Thu 7/17/97	Thu 1/15/98	90%	C,DJH,GAE	
4	**Sales preliminary sales order**	1d	Mon 1/26/98	Mon 1/26/98	0%		
5	**Major component selection**	40d	Tue 1/27/98	Mon 3/23/98	0%		4
6	Generator and drive system	8d	Tue 1/27/98	Thu 2/5/98	0%	GAE	
7	Air conditioning	5d	Fri 2/20/98	Thu 2/26/98	0%	GAE	
8	PLC	3d	Tue 1/27/98	Thu 1/29/98	0%	DJH,MWC	
9	Batteries	10d	Fri 2/27/98	Thu 3/12/98	0%	GAE,MWC	
10	Engine	15d	Fri 2/6/98	Thu 2/26/98	0%	RWQ	1,6
11	CNG tanks	8d	Fri 2/27/98	Tue 3/10/98	0%	HN	10
12	Fan Drive for engine	5d	Wed 3/11/98	Tue 3/17/98	0%	HN,CDM	10
13	Radiator	4d	Wed 3/18/98	Mon 3/23/98	0%	CDM	12
14	Fire suppression system	1d	Fri 2/13/98	Fri 2/13/98	0%	GAE,HN	
15	Electronic cooling system radiator	5d	Fri 2/6/98	Thu 2/12/98	0%	CDM	6
16	**Design**	211d	Sun 2/15/98	Mon 12/7/98	0%		5
17	**Electrical design**	211d	Sun 2/15/98	Mon 12/7/98	0%		
18	SYSTEMS CHART	5d	Sun 2/15/98	Fri 2/20/98	0%	MWC	
19	GENERATOR INTERFACE	10d	Tue 3/24/98	Mon 4/6/98	0%	MWC	
20	AIR CONDITIONING SYSTEM	10d	Tue 4/7/98	Mon 4/20/98	0%	MWC	1,2,19
21	HIGH VOLTAGE POWER DISTRIBUTION PANEL/SYSTEM	12d	Mon 5/18/98	Tue 6/2/98	0%	MWC	2,20
22	ELECTRICAL CONTROL SYSTEM	60d	Wed 6/3/98	Tue 8/25/98	0%	MWC	1,2,21
23	ANTILOCK BRAKING INTERFACE	2d	Wed 8/26/98	Thu 8/27/98	0%	MWC	22
24	HIGH VOLTAGE POWER CABLES	12d	Fri 8/28/98	Mon 9/14/98	0%	MWC	23,2
25	HARNESSES	30d	Tue 9/15/98	Mon 10/26/98	0%	MWC	2,24

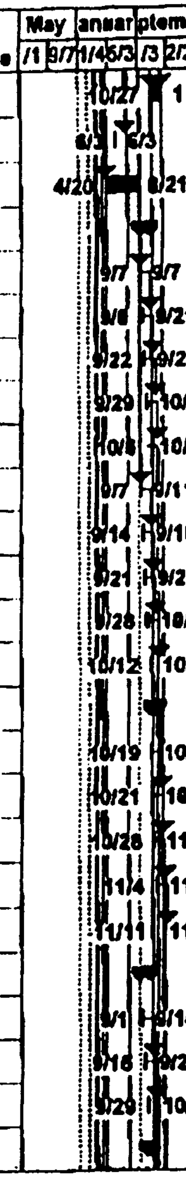


Project: FOOTHILL/GILLIG HYBRID
Date: Thu 2/5/98

Task	Summary	Rolled Up Progress	
Progress	Rolled Up Task		
Milestone ◆	Rolled Up Milestone ◇		

FOOTHILL/GILLIG HYBRID ELECTRIC BUS

ID	Task Name	Duration	Start	Finish	% Complet	Resource I	Predece
26	CUSTOM INTERFACE ELECTRONIC BOARDS	30d	Tue 10/27/98	Mon 12/7/98	0%	MWC	2,25
27	DECALS-WARNING, HIGH VOLTAGE, CNG, ETC.	1d	Wed 6/3/98	Wed 6/3/98	0%	MKY	21
28	A-B PROGRAM CODE FOR VEHCILE	90d	Mon 4/20/98	Fri 8/21/98	0%	DJH	2
29	Engine Installation (Eng. and drive train)-MECHANICAL	30d	Mon 9/7/98	Fri 10/16/98	0%		
30	Engine Spec	1d	Mon 9/7/98	Mon 9/7/98	0%	CDM	10
31	Engine/Generator mounting	10d	Tue 9/8/98	Mon 9/21/98	0%	CDM	30
32	Radiator mounting	5d	Tue 9/22/98	Mon 9/28/98	0%	CDM	31
33	Motor mounting	5d	Tue 9/29/98	Mon 10/5/98	0%	CDM	32
34	Driveline	1d	Tue 10/6/98	Tue 10/6/98	0%	CDM	33
35	Inverter mounting	5d	Mon 9/7/98	Fri 9/11/98	0%	DPH	6
36	Inverter resistor and engine cooling system	5d	Mon 9/14/98	Fri 9/18/98	0%	DPH	35
37	Engine cooling system	5d	Mon 9/21/98	Fri 9/25/98	0%	DPH	36
38	Rear frame drilling/configuration	10d	Mon 9/28/98	Fri 10/9/98	0%	DPH	37
39	Freon compressor mounting	5d	Mon 10/12/98	Fri 10/16/98	0%	DPH	38
40	Chassis	19d	Mon 10/19/98	Thu 11/12/98	0%		
41	Chassis layout	2d	Mon 10/19/98	Tue 10/20/98	0%	CCM	
42	Battery mounting	5d	Wed 10/21/98	Tue 10/27/98	0%	CCM	41
43	Cng tank mounting	5d	Wed 10/28/98	Tue 11/3/98	0%	CCM	42
44	Inverter mounting	5d	Wed 11/4/98	Tue 11/10/98	0%	CCM	43
45	Center frame drilling	2d	Wed 11/11/98	Thu 11/12/98	0%	CCM	44
46	Systems Design	30d	Tue 9/1/98	Mon 10/12/98	0%		
47	Cng piping	10d	Tue 9/1/98	Mon 9/14/98	0%	HN	
48	Fan Drive	10d	Tue 9/15/98	Mon 9/28/98	0%	HN	47
49	Air conditioning	10d	Tue 9/29/98	Mon 10/12/98	0%	HN	48
50.	Body Design	15d	Thu 10/1/98	Wed 10/21/98	0%		

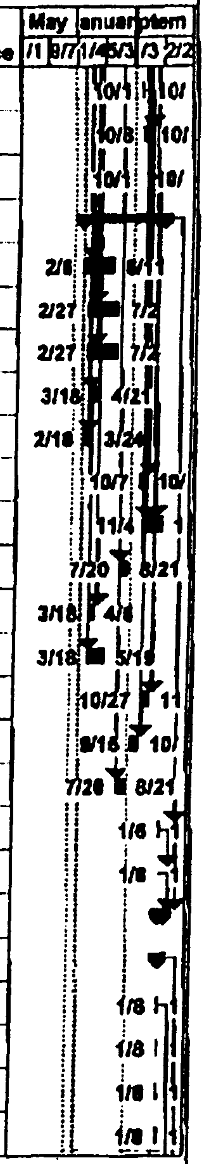


Project: FOOTHILL/GILLIG HYBRID
Date: Thu 2/5/98

Task | Progress | Milestone ◆ | Summary | Rolled Up Task | Rolled Up Milestone ◇ | Rolled Up Progress

FOOTHILL/GILLIG HYBRID ELECTRIC BUS

ID	Task Name	Duration	Start	Finish	% Complet	Resource I	Predece
51	Air conditioning mounting	5d	Thu 10/1/98	Wed 10/7/98	0%	TWA	
52	Drivers Banier/electrical box	10d	Thu 10/8/98	Wed 10/21/98	0%	TWA	51
53	Seat layout	1d	Thu 10/1/98	Thu 10/1/98	0%	AY	
54	Procurement	238d	Fri 2/6/98	Tue 1/5/99	0%		
55	ORDER GENERATOR MOTORS, GEAR BOX , INVERTERS AND RESISTOR FR	90d	Fri 2/6/98	Thu 6/11/98	0%		6
56	ORDER ENGINE FROM CUMMINS/DDC	90d	Fri 2/27/98	Thu 7/2/98	0%		10
57	ORDER AIR CONDITIONER	90d	Fri 2/27/98	Thu 7/2/98	0%		7
58	ORDER FIRE SUPRESSION SYSTEM	25d	Wed 3/18/98	Tue 4/21/98	0%		2
59	ORDER A-B PLC	25d	Wed 2/18/98	Tue 3/24/98	0%		8
60	ORDER DRIVELINE	15d	Wed 10/7/98	Tue 10/27/98	0%		34
61	ORDER CNG TANKS AND FITTINGS	45d	Wed 11/4/98	Tue 1/5/99	0%		43,47
62	ORDER VOLTAGE MONITORS TO INTERFACE TO PLC	25d	Mon 7/20/98	Fri 8/21/98	0%		2
63	ORDER THERMOCOUPLE	14d	Wed 3/18/98	Mon 4/6/98	0%		9
64	ORDER BATTERIES	45d	Wed 3/18/98	Tue 5/19/98	0%		6
65	ORDER HARNESSES	20d	Tue 10/27/98	Mon 11/23/98	0%		25
66	ORDER CABLES	20d	Tue 9/15/98	Mon 10/12/98	0%		24
67	ORDER HALL EFFECT CURRENT SENSORS	25d	Mon 7/20/98	Fri 8/21/98	0%		6
68	DESIGN REVIEW BEFORE PRODUCTION	2d	Wed 1/6/99	Thu 1/7/99	0%		54
69	VIN DEFINITION	0.2d	Fri 1/8/99	Fri 1/8/99	0%	RWQ	68
70	Start Production	16d	Fri 1/8/99	Mon 2/1/99	0%		69,54
71	DEPT 64-CHASSIS	3d	Fri 1/8/99	Wed 1/13/99	0%		
72	TEST BATTERIES AND MOUNT SENSORS	1d	Fri 1/8/99	Mon 1/11/99	0%		
73	DRILL RAIL	1d	Fri 1/8/99	Mon 1/11/99	0%		
74	SUSPENSION	1d	Fri 1/8/99	Mon 1/11/99	0%		
75	INSTALL CNG ENGINE AND GENERATOR	1d	Fri 1/8/99	Mon 1/11/99	0%		



Project: FOOTHILL/GILLIG HYBRID
Date: Thu 2/5/98

Task — Progress — Milestone ◆ — Summary — Rolled Up Task — Rolled Up Milestone ◇ — Rolled Up Progress

FOOTHILL/GILLIG HYBRID ELECTRIC BUS

ID	Task Name	Duration	Start	Finish	% Complet	Resource I	Predece	May /1 9/7 anuar 1/4 5/3 ptem /3 2/2
76	PIPING AND ELECTRICAL	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
77	INSTALL BATTERIES AND BATTERY TRAYS	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
78	INSTALL BATTERY SOLENIODS & CABLES	1d	Mon 1/11/99	Tue 1/12/99	0%		72	1/11
79	INSTALL BRAKING RESISTOR	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
80	INSTALL IGBT CONTROLLERS/INVERTERS	2d	Fri 1/8/99	Tue 1/12/99	0%			1/8
81	INSTALL CONTROL WIRING	1d	Tue 1/12/99	Wed 1/13/99	0%		80	1/12
82	INSTALL FIRE SUPRESSION SYSTEM	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
83	MOUNT THERMOCOUPLES, VOLTAGE SENSORS AND CURRENT SENSO	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
84	WIRING HIGH VOLTAGE SYSTEM	1d	Tue 1/12/99	Wed 1/13/99	0%		80,85	1/12
85	INSTALL MOTORS AND GEAR BOX	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
86	INSTALL A-B PLC IN CHASSIS	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
87	INSTALL INVERTER COOLING SYSTEM	1d	Fri 1/8/99	Mon 1/11/99	0%			1/8
88	Dept -05-ROOF	1d	Wed 1/13/99	Thu 1/14/99	0%		71	
89	INSTALL AIR CONDITIONING SYSTEM	1d	Wed 1/13/99	Thu 1/14/99	0%		87	1/13
90	install sidewalls and roof	1d	Wed 1/13/99	Thu 1/14/99	0%			1/13
91	Dept -06	2d	Thu 1/14/99	Mon 1/18/99	0%		88	
92	install gauges	1d	Thu 1/14/99	Fri 1/15/99	0%			1/14
93	install flooring	1d	Thu 1/14/99	Fri 1/15/99	0%			1/14
94	INSTALL PLC IN BODY	2d	Thu 1/14/99	Mon 1/18/99	0%			1/14
95	install font and rear cap	1d	Thu 1/14/99	Fri 1/15/99	0%			1/14
96	Dept 07 paint	4d	Mon 1/18/99	Fri 1/22/99	0%		91	1/18
97	Dept -08-trim	2d	Fri 1/22/99	Tue 1/26/99	0%		96	
98	Windows	1d	Fri 1/22/99	Mon 1/25/99	0%			1/22
99	Seats	1d	Mon 1/25/99	Tue 1/26/99	0%		98	1/25
100	Dept 10 final	4d	Tue 1/26/99	Mon 2/1/99	0%		97	

Project: FOOTHILL/GILLIG HYBRID
Date: Thu 2/5/98

Task — Progress — Milestone ◆ — Summary — Rolled Up Task — Rolled Up Milestone ◇ — Rolled Up Progress

FOOTHILL/GILLIG HYBRID ELECTRIC BUS

ID	Task Name	Duration	Start	Finish	% Complet	Resource I	Predece	May /1, 9/7, anuar 1/4, 5/3, ptem /3, 2/2
101	system check/misc.	1d	Tue 1/26/99	Wed 1/27/99	0%			1/26
102	Alignment	1d	Wed 1/27/99	Thu 1/28/99	0%		101	1/27
103	FINISH ASSEMBLY OF VEHICLE	2d	Thu 1/28/99	Mon 2/1/99	0%		102	1/28
104	SYSTEM CHECKS	23d	Mon 2/1/99	Thu 3/4/99	0%		103	
105	SAFETY SYSTEMS CHECK	5d	Mon 2/1/99	Mon 2/8/99	0%		103	2/1
106	PLC systems check	5d	Mon 2/1/99	Mon 2/8/99	0%			2/1
107	TEST FIRE SUPRESSION SYSTEM	1d	Mon 2/1/99	Tue 2/2/99	0%		103	2/1
108	FUEL VEHICLE AND LEAK TEST	2d	Tue 2/2/99	Thu 2/4/99	0%		107	2/2
109	THROTTLE ADJUSTMENT	3d	Thu 2/4/99	Tue 2/9/99	0%		108	2/4
110	COOLING TEST- ENGINE	2d	Tue 2/9/99	Thu 2/11/99	0%		109	2/9
111	WEIGHT OF VEHICLE	1d	Thu 2/4/99	Fri 2/5/99	0%		108	2/4
112	SEIMENS/VOITH COMMISION AND TESTING	10d	Thu 2/4/99	Thu 2/18/99	0%		108	2/4
113	VEHICLE TESTING	10d	Thu 2/18/99	Thu 3/4/99	0%		112	2/18

Project: FOOTHILL/GILLIG HYBRID
Date: Thu 2/5/98

Task — Summary — Rolled Up Progress
Progress — Rolled Up Task
Milestone ◆ — Rolled Up Milestone ◇

HYBRID ELECTRIC BUS PROJECT
Foothill Transit and Gillig Corporation

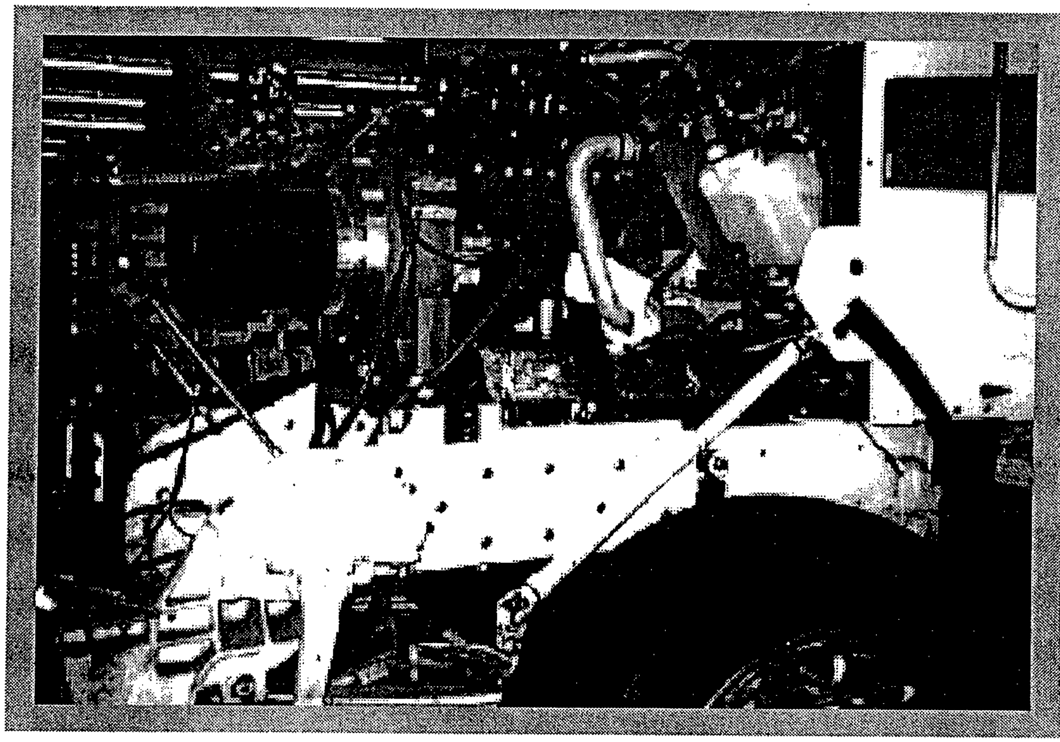
EXHIBIT A
BUDGET/SCHEDULE/MILESTONES (Preliminary)

			PRELIMINARY BUDGET		
DUE DATE	TASK	DESCRIPTION OF MILESTONES	MATCH FUNDS	DARPA FUNDS	TOTAL
3/31/98	Quarterly Report Begin System Designs	Finalize Design Parameters Select Major Components	$ -	$ -	$ -
6/30/98	Quarterly Report Procurement System Designs	Order Major Components	$ 18,061	7,939	$ 26,000
9/30/98	Quarterly Report Procurement System Designs	Electrical System Design	$ 22,229	9,771	$ 32,000
12/31/98	Quarterly Report Procurement System Designs	Design Engine Installation-Mechanical	$ 153,519	67,481	$ 221,000
3/31/99	Quarterly Report	Build Vehicle System Checks Emissions Tests	$ 208,397	91,603	$ 300,000
6/31/99	Quarterly Report Field Test	Field Test	$ 18,061	7,939	$ 26,000
9/30/99	Final Report		$ 34,733	15,267	$ 50,000
		TOTALS	$ 455,000	$ 200,000	$ 655,000

Quarterly reports are required with eaach invoice. Invoices should be submitted earlier if Task is achievedd in advance of the milestone date.
CALSTART's general policy is to withhold 10% of the total funding, pending approval of the final report, government audit and/or contract closure.

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

Status Update:
March 1998



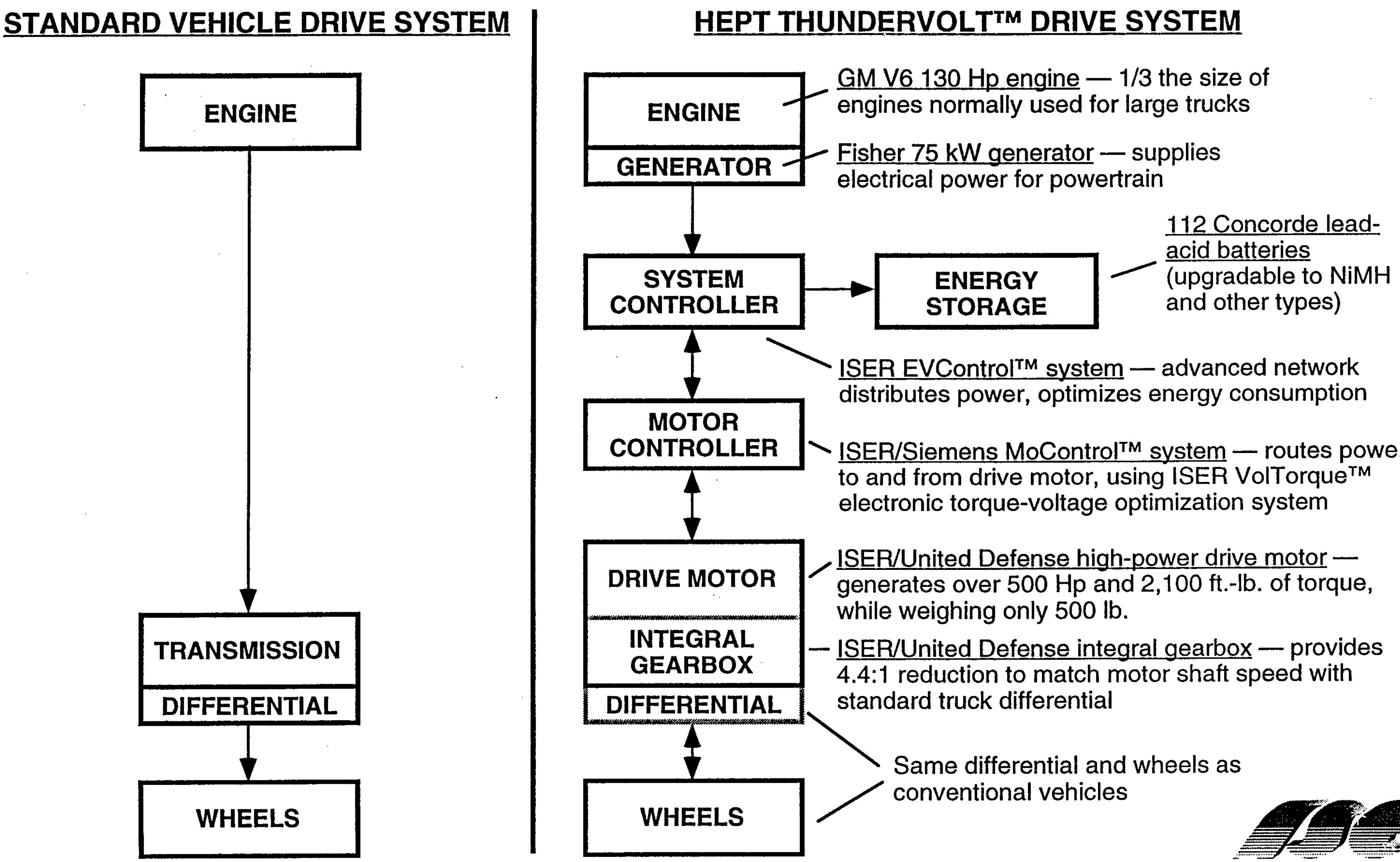
Working w/ Hackney & Sons – the largest mfger. of bottle trucks; McKesson & Sparkletts – 2 doing trucking for both.

RESEARCH

ISE Research Corporation
4909 Murphy Canyon Road, Suite 220
San Diego, CA 92123-4300
(619) 637-5777
http://www.isecorp.com

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

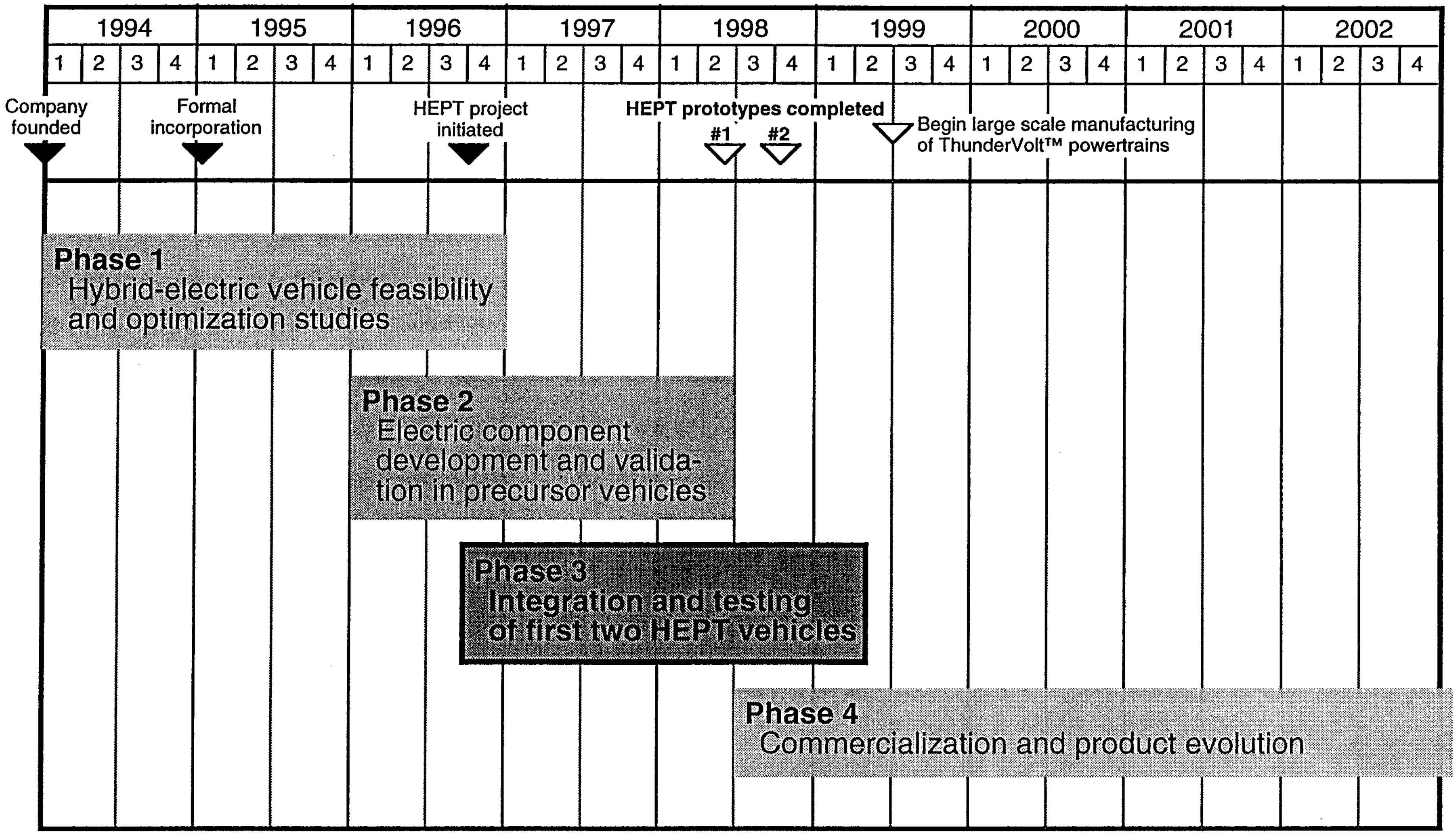
HEPT POWERTRAIN AT A GLANCE



March 1998 Status

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

HEPT DEVELOPMENT SCHEDULE



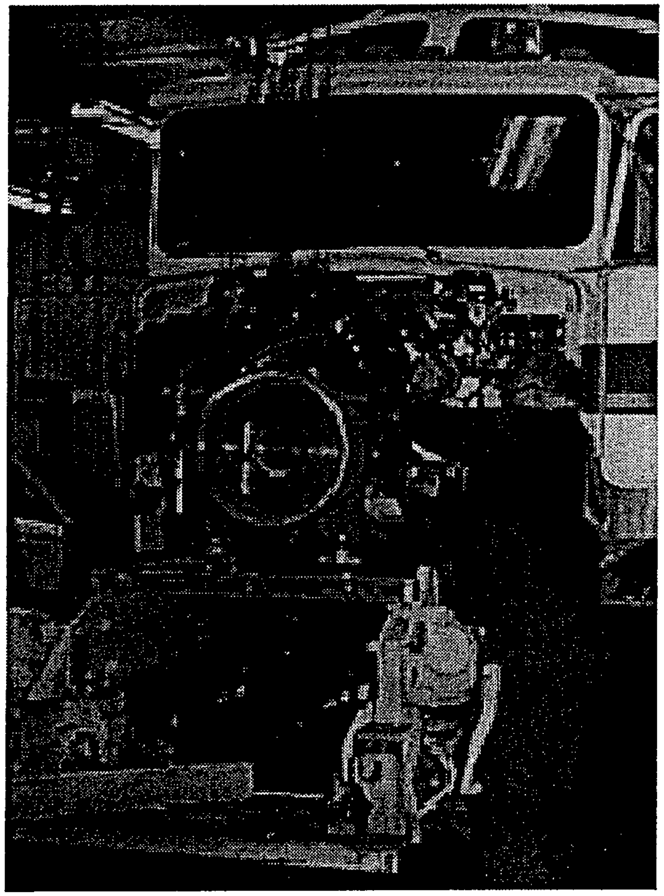
Signed deal w/ an investment bank to raise $6M in debt & equity capital.

March 1998 Status

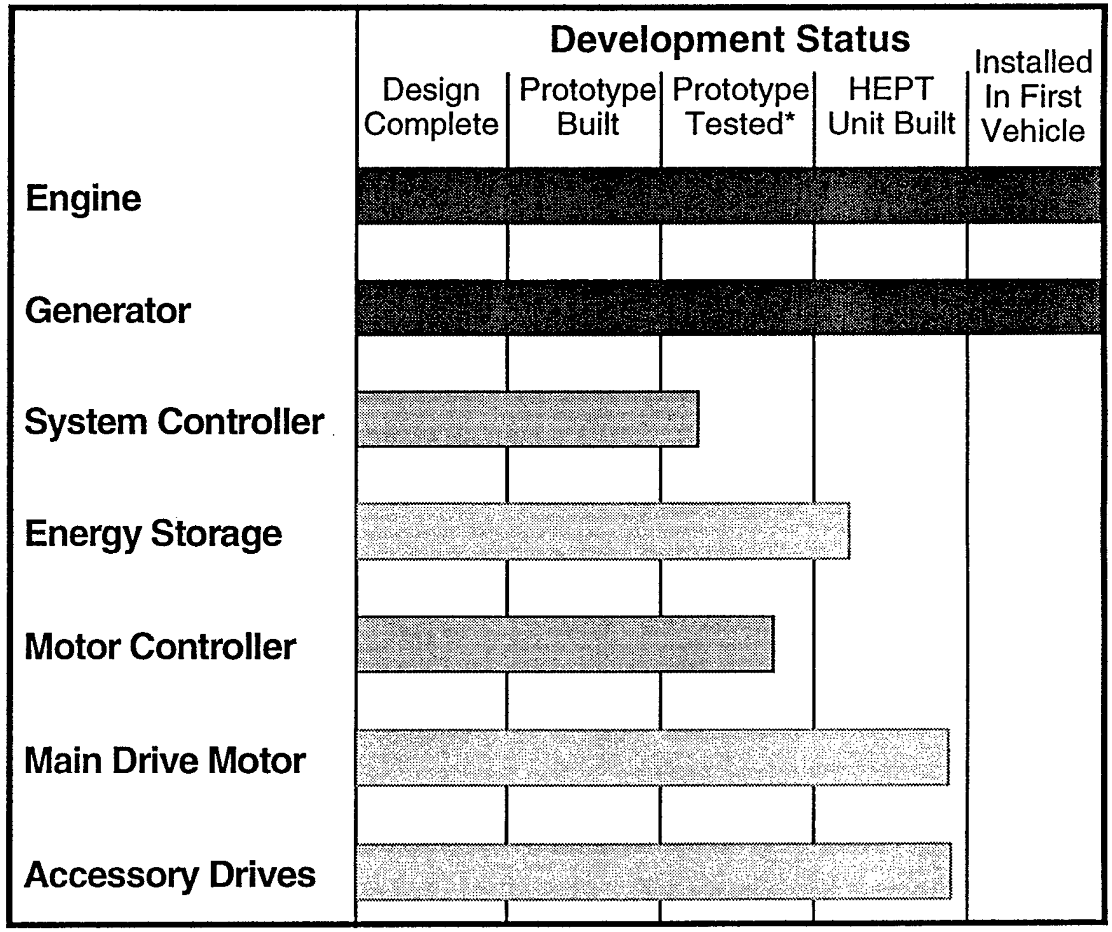
RESEARCH

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

STATUS OF THE MAJOR COMPONENTS



First HEPT vehicle under assembly



* Prototype of HEPT component tested in precursor electric vehicle

ENGINE/GENERATOR (APU*)

*APU = auxiliary power unit.
First vehicle APU assembly shown.

Lockheed-Martin

West Coast presence.
Navistar rel.
250 hp. - class 7 trucks

ISE
Kenworth rel.
class 8 trucks & mil. vehicles.

Development status:

- **Engine installed into vehicle — June 1997**
- **Generator mated to engine — July 1997**
- **APU tested to full power (75 kW) — October 1997**

Performance goals:

- **CNG fuel efficiency: 6-8 gal/hr @ 65 kW (Up to 10 mpg, depending on driving cycle)** vs. 6
- **Emissions: 4.1 grams NOX/mile when APU is on (50-75% time), based on engine tests**
- **Reduced maintenance, based on engine use 50-75% time at constant 2,400-2,800 RPM**

w/ lead acid batteries
→ all performance goals assume

APU can be turned off. LMC can't run on batteries alone

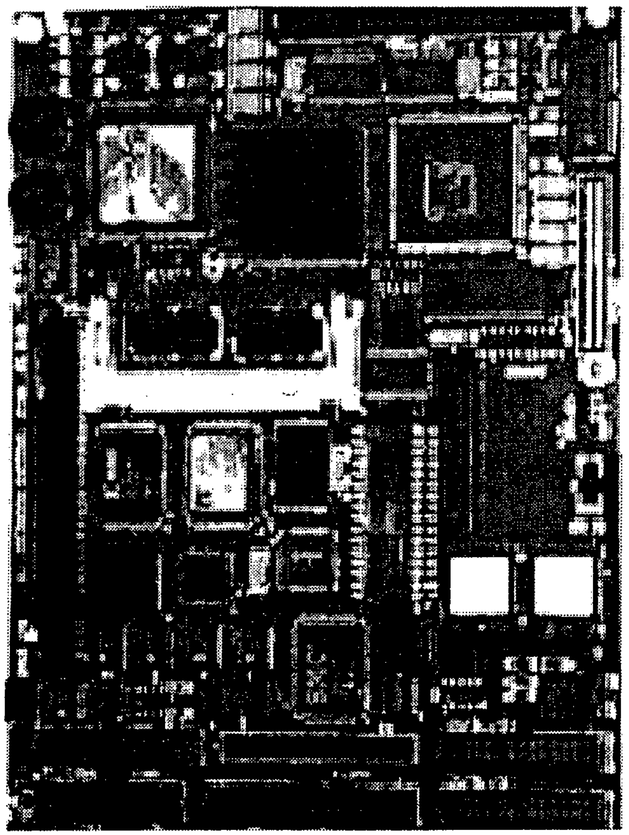
CALSTART

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

DARPA

SYSTEM CONTROLLER (EVControl™)

Connect w/ APRCI? DEMS?



Central microprocessor for ThunderVolt™ EVControl™ electric vehicle control system

Development status:

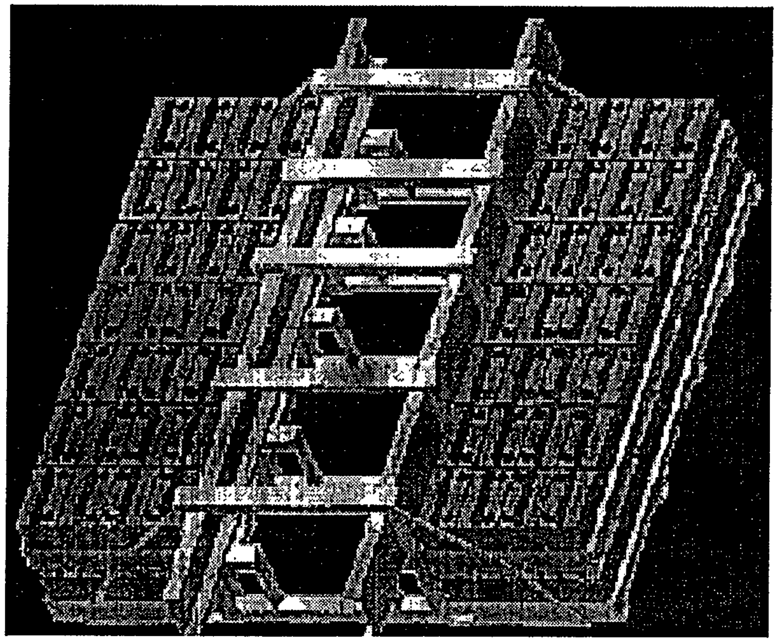
- HEPT control architecture defined
- "Phase 1" prototype control system installed in electric airport tow tractor — Sept 1997
- "Phase 2" prototype control system installed in electric Class 7 truck — March 1998
- First module for advanced EVControl™ network partially constructed
- Electric Vehicle Operating System™ (EVOS™) software being written
- EVControl™ network to be installed in HEPT Vehicle 1 in April-May 1998

Performance goals:

- Monitor status of all vehicle subsystems
- Display operating and diagnostics data to vehicle operator
- Optimize energy consumption, including use of global positioning data to predict use
- Store vehicle performance data for analytical use

ISE RESEARCH

ENERGY STORAGE SYSTEM



Battery rack design for installation of 112 batteries onto HEPT Kenworth T-800 trucks

Development status:

- Prototype 112 battery set installed into electric Class 7 truck — December 1997
- Battery rack structure design completed and under evaluation by PACCAR/ Kenworth
- Batteries for first HEPT vehicle delivered
- Advanced battery management (charge equalization) system under development

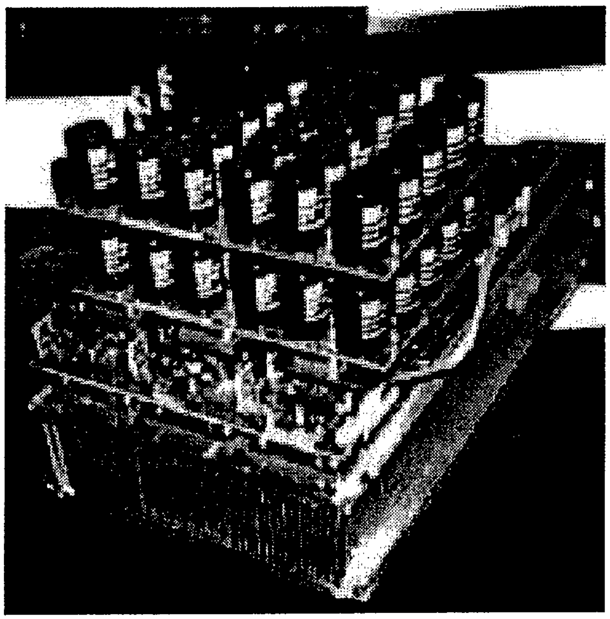
Performance goals:

- Supply 672 VDC in two sets of 56 (12V, sealed lead-acid) batteries
- Supply up to 300 kW to augment APU during peak power loads
- Enable all-electric operation of locally operated trucks through deep-cycling (to 20% state-of-charge)

6,000 lbs. of batteries

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

THUNDERVOLT ™ MOTOR CONTROLLER


Power module for ThunderVolt™ motor control subsystem

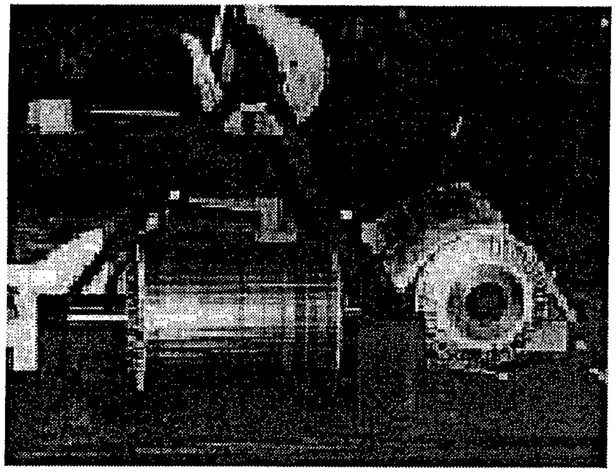
Development status:
- **Modular control architecture defined**
- **Testing of multiple 100 kW modules at partial power accomplished**
- **Prototype VolTorque™ high-power switching device built and bench-tested**
- **Interface with Vehicle Dynamics Controller™ partially complete**
- **MC270 controller to be installed in electric Class 7 Vehicle in April 1998, with MC400 controller into first HEPT vehicle in May 1998**

Performance goals:
- **Convert 672 VDC to 543 VAC**
- **Handle current loads of up to 500 amps**
- **Supply high power (300 kW/400 Hp continuous, 420 kW peak) to main drive motor (MC400)**
- **Channel regenerative braking energy to energy storage subsystem**

Critical path item
Longest lead time

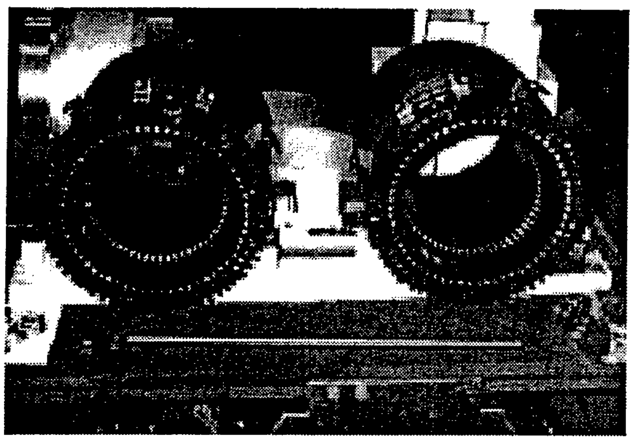
RESEARCH

AC500 HIGH POWER DRIVE MOTOR



Development status:

- Earlier versions of motor were built by United Defense in mid-1997
- ISER-sponsored redesign of motor (to use VolTorque™ control) completed in Dec 1997
- Parts for first three ISER motors fabricated
- First motor assembled, to be installed into ISER electric Class 7 truck in Apr 1998
- Second motor to be assembled in April 1998, installed into HEPT Vehicle #1 in May 1998

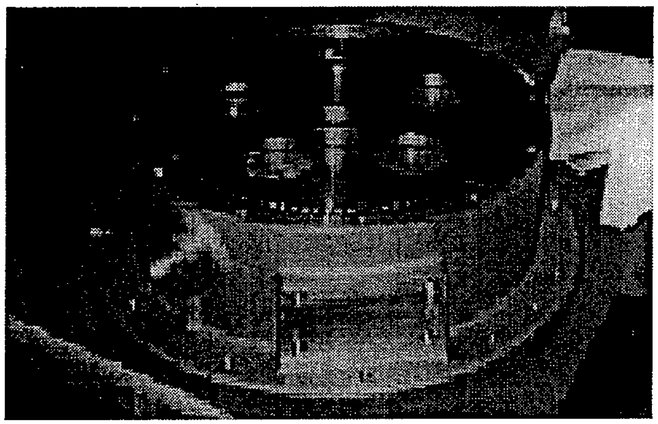


Performance goals:

- Supply 300 kW continuous (402 Hp) and 388 kW peak (520 Hp) at 95% peak efficiency
- Provide 2,100 ft.-lb. torque at up to 1,125 RPM
- Maximum speed of 14,000 RPM (to 20% state-of-charge)
- Enable regenerative braking

ISE RESEARCH

MAJOR SUBSYSTEMS

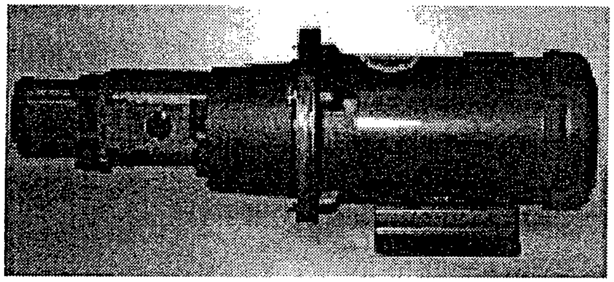


Integral Gearbox
- Planetary 4.4:1 gear reduction system
- Compact package integrated with drive motor
- Reduces motor shaft speed to under 3,000 RPM

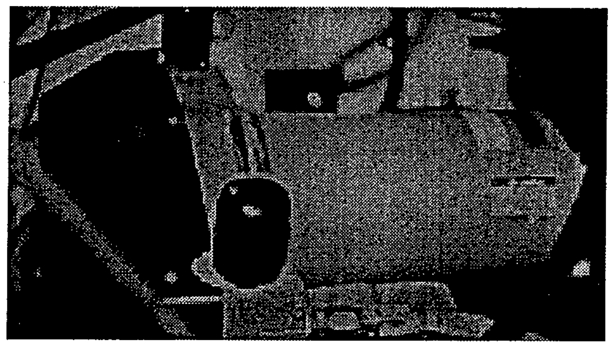
Vehicle Dynamics Controller™
- Key element of EVControl™ system
- Regulates motor speed using accelerator pedal
- Governs mix of regular & regenerative braking

Electric Vehicle Operating System™ (EVOS™)
- Software and standards governing use of "plug-in" EVControl™ modules
- Highly proprietary — details to be released in late 1998

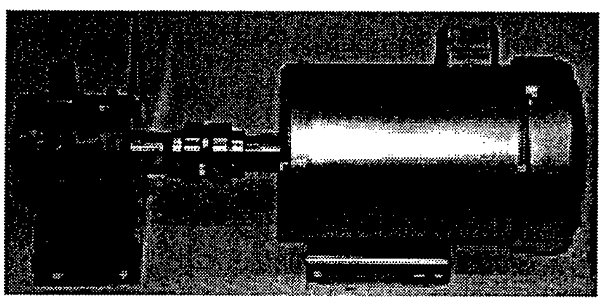
ELECTRICALLY-DRIVEN ACCESSORIES



Power Steering
- Uses electric motor to drive hydraulic pump, providing pressure for actuation of steering systems
- More efficient than conventional power steering units



Power Braking
- Uses electric motor to drive an air compressor, providing air for actuation of braking systems
- More efficient than conventional braking units (direct-driven, supplies power on demand)



Heating, Ventilation, and Air Conditioning
- Uses electric motor to drive an air conditioning compressor
- More efficient than conventional systems (direct-driven, supplies power on demand)

CALSTART

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

DARPA

PROJECTED OPERATIONAL BENEFITS

Benefit Category	Major Benefits	Key Reasons for Benefits
Emissions	• 64-96% reduction in NOX • 49-92% reduction in CO • 58-94% reduction in NMHC • 80-90% reduction in PM	• Smaller, more efficient engine • Clean-burning fuel • Periodic all-electric operation
Energy Efficiency	• 30-60% lower fuel consumption • 15-30% lower overall energy use	• Engine output more closely linked with vehicle power use • Regenerative braking • Aerodynamic improvements
Performance	• 28% faster acceleration (0-60 mph) • 7-8% increase in cargo volume	• Constant motor torque vs. RPM • Ability to lower vehicle frame
Maintenance	• 30% increase in major maintenance intervals • 15-25% reduction in average maintenance time • 50-75% reduction in brake wear	• Simpler engine operating within a more narrow range • Regenerative braking
Life-Cycle Cost	• 10-20% reduction in life-cycle cost	• Lower fuel consumption • Lower maintenance costs

RESEARCH

SUMMARY OF HEPT-DERIVED PRODUCTS
With Potentially Broad Utility and Commercial Potential

Auxiliary Power Unit (APU)
- Custom 75 kW alternator/generator
- SAE-standard engine-generator interface kit

Motive Drive System
- ThunderVolt™ AC500 high power AC drive motor
- ThunderVolt™ MC series of modular motor controllers
- VolTorque™ torque-voltage optimization system

Energy Storage System
- Integrated 576VDC and 672 VDC battery packs
- Automatic Continuous Equalization System™ (ACES™)

Vehicle Control System
- EVControl™ distributed network for vehicle control
- Various network nodes (e.g., battery monitoring, APU control, etc.)
- Electric Vehicle Operating System™ (EVOS™)
- Vehicle Dynamics Controller™ for electric acceleration and braking

HYBRID-ELECTRIC PROTOTYPE TRUCK (HEPT)

FUTURE NEEDS

For Successful Commercialization of Technology

Auxiliary Power Unit (APU) → RR say if do it -- it's an add-on to their Air Force contract.

- More affordable alternator/generator
- Ideal: Efficient, cost-effective turbogenerator or fuel cell

Motive Drive System

- Improved leak-proofing of drive motor
- Motor parts cost reduction
- Robust, simplified gear reduction system

FY98 Proposal

Energy Storage System

- More versatile, cost-effective battery recharging system*
- Affordable, higher energy density batteries

Needs to better explain the benefits/need for of this technology.

Vehicle Control System

- Improved capabilities for energy prediction
- Improved operator interface

RR asked Simon to tell him what the industry needs & what should the govt. be doing.

* Critical near term need

March 1998 Status

RESEARCH

Active Damping and Ride Height Control

PROJECT: Active Damping and Ride Height Control for High Performance Off-Road Vehicles

PARTICIPANTS: Rod Millen Special Vehicles

with

AeroVironment

CALSTART

Active Damping and Ride Height Control

DARPA

OBJECTIVES: Develop a Computer Controlled Suspension for High Performance Off-Road Vehicles.

- Improved Isolation
- Improved Vehicle Stability
- Improved Traction
- Energy Efficient
- Safe Soft Failure Modes

Better than UT technology *

PURPOSE: To increase both a vehicles' absorbed power ride limiting speed peak acceleration limiting speed

Active Damping and Ride Height Control

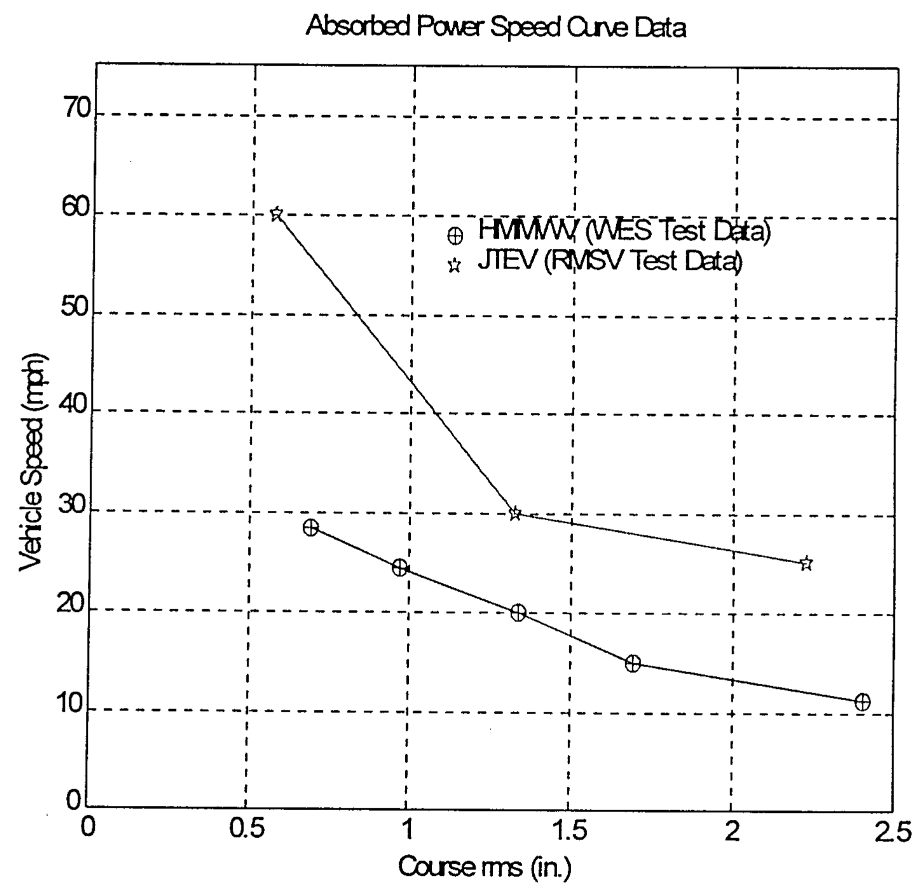
Accomplishments

- Completed Detail Design of Control System Algorithm for JTEV
- Completed Detail Design of Control System Hardware for JTEV
- Completed Detail Design of Active Damper Hardware for JTEV
- Completed Detail Design of Active Ride Height Hardware for JTEV

Active Damping and Ride Height Control

PROBLEMS ENCOUNTERED:

- JTEV unavailibilty
  back East since Sept.
- JTEV already has excellent passive suspension
- NSWC/CARDEROCK suggested Hybrid Electric HMMWV as platform



Active Damping and Ride Height Control

CALSTART

DARPA

BENEFITS OF REDIRECTION:

- GFE HMMWV can be used for integration and preliminary testing
- Potential COMBATT application
- Gives excellent and direct comparision between many different suspension technologies
  - Univ. of Texas Electromagnetic suspension
  - Lotus Active suspension
  - RMSV High Performance passive suspension

Commercially Based Tactical Truck – Edison nny [illegible] program. Enviro. Research Institute of Michigan

Active Damping and Ride Height Control

CALSTART

DARPA

CURRENT STATUS AND IMPLEMENTATION:

- Most hardware is applicable
- Computer modeling needs to be modified
- Damper redesign is required for HMMWV
- Redesigned damper needs to be tested
- Feasibility study for adding roll control system to HMMWV
- Modification to control program and additional computer simulation
- Additional funding for testing and development is recommended

HMMWV much wider than JTEV or RSTV

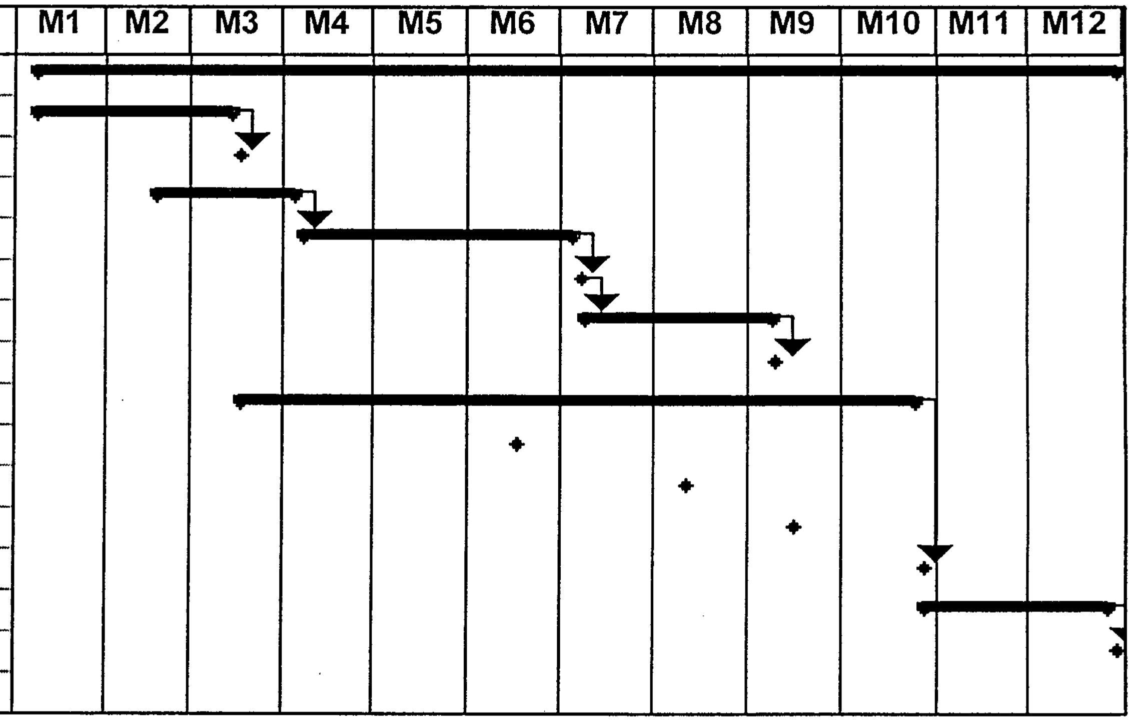
Active Damping and Ride Height Control

Work Overview

FY '95 (COMPLETED)	FY '96 (WORK STARTED 1/97, REDIRECTION CONSIDERED 12/97)	FY '98 (CURRENT PROPOSAL)
• Computer Model Development • System Configuration Analysis • Determination of Critical System Variables • Baseline Damper Testing	• Active Damper Prototype Development and testing • Control Code writing and debugging for basic control algorithm • Integrate System into vehicle, which was JTEV but due to lack of availability redirected to HMMWV • Sensed Variables: Suspension Deflection Suspension Velocity Body Vertical Acceleration	• Develop advanced suspension control algorithms • Testing and optimization of suspension system over real-world terrain • Sensed Variables: Suspension Deflection Suspension Velocity Vehicle Speed Steering Angle Brake/Throttle Position Body Vertical Acceleration Body Roll Rate Body Pitch Rate Body Yaw Rate

Active Damping and Ride Height Control

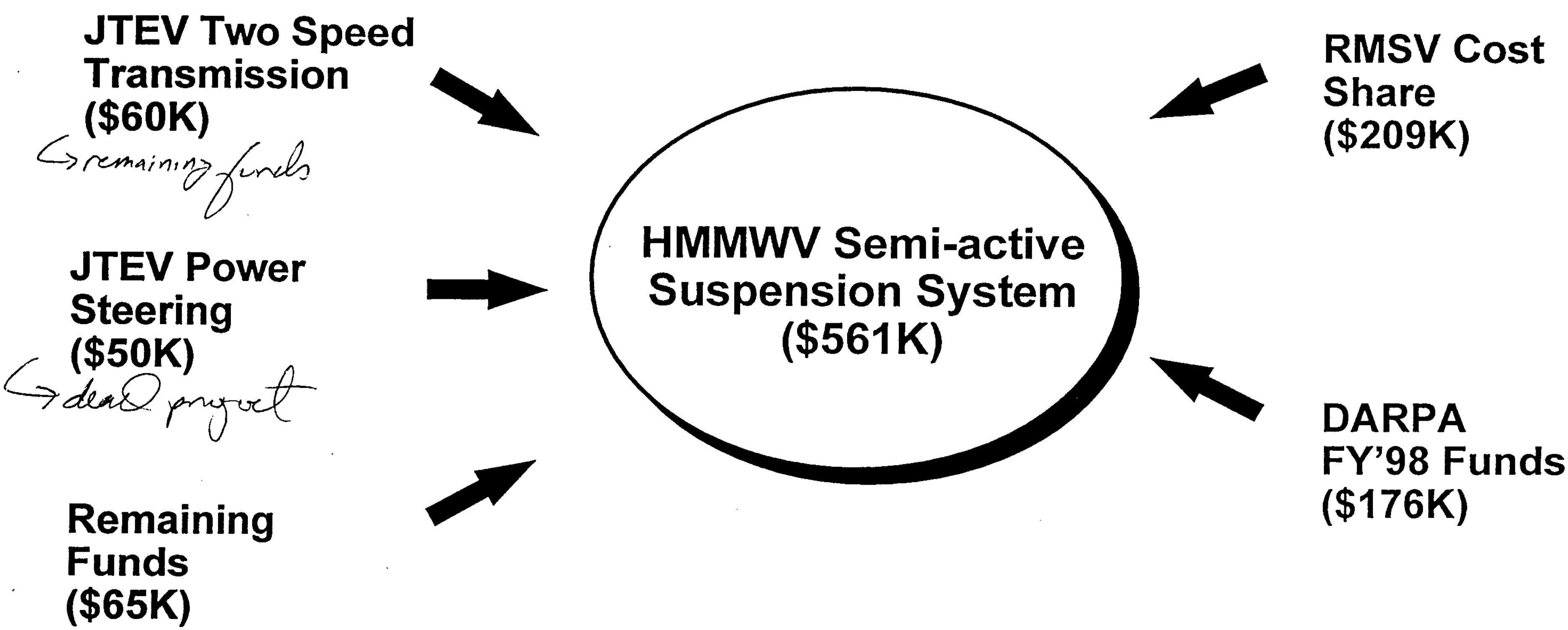
ID	Task Name
1	HMMWV Semi Active Suspension
2	Redesign
6	Design complete
7	Procure material
32	Fabricate
36	Component fab complete
37	Vehicle Integration
66	System intg complete
67	Testing
81	Shock dyno testing complete
82	System testing complete
83	Vehicle testing complete
84	Devlpmnt/Test/Eval complete
85	Reporting
89	Submit final report



Active Damping and Ride Height Control

CALSTART

DARPA



CALSTART

Active Damping and Ride Height Control

DARPA

HMMWV Semi-active Suspension - Sources of Funds

Milestones	Prior Allocated Funding	RMSV Cost Share	RMSV In-kind Costs	DARPA Funding	Total
HMMWV Redesign	49,216	13,375			62,591
Fabrication	48,111	6,500			54,611
Vehicle Integration	18,918				18,918
Shock Dyno Testing	14,615	40,000	150,000		204,615
System Testing	19,500				19,500
Vehicle Evaluation	12,040			42,960	55,000
System Optimization				125,000	125,000
Reporting	12,600			8,501	21,101
Total	$ 175,000	$ 59,875	$ 150,000	$ 176,461	$ 561,336

CALSTART

Active Damping and Ride Height Control

DARPA

HMMWV Semi-active Suspension - Uses of Funds									
	HMMWV Redesign	Fabrication	Vehicle Integration	Shock Dyno Testing	System Testing	Vehicle Evaluation	System Optimization	Reporting	Total
Labor	11,698	6,785	6,468	13,675	6,667	18,034	36,974	4,308	104,609
Materials	10,288	26,765		3,846			12,962	769	54,630
Subcontracts	11,538								11,538
Travel								5,769	5,769
Facilities				68,244		2,250			70,494
Overhead	29,066	21,061	12,450	118,849	12,833	34,716	75,064	10,255	314,295
Total	62,591	54,611	18,918	204,615	19,500	55,000	125,000	21,101	561,336

Active Damping and Ride Height Control

CALSTART

DARPA

MARKET ANALYSES

MILITARY/CIVILIAN APPLICATIONS:

Improved performance over passive suspension:

- improved isolation
- reduction in body resonance motions
- improved tire traction
- improved adaptability
- improved vehicle load rejecion

PROJECT UNIT COST IN MARKETPLACE:

Unknown (dependent on total qty/rate)

CALSTART

Active Damping and Ride Height Control

DARPA

COMMERCIAL OPPORTUNITY

- Total Domestic SUV/Truck Market — 5,180,000 units/year
  - Chrysler — 1,336,000
  - Ford — 1,852,000
  - GM — 1,992,000
- Military HMMWV Fleet — >100,000 existing
- RST-V – RMSV Teaming w/ AV & LMC — 328 planned
- FSV – Army Future Scout Vehicle – 16K lbs. — 1000 planned
- LSV – Light Strike Vehicle Diesel only – not hybrid — 373 planned (44 to Special Forces)
- COMBATT/ERIM
  - GM, Ford, Chrysler, AM General

AeroVironment Inc.

Fuel Efficiency Test Procedure

- Objective
  - Develop a Standard, Reproducible and Representative Procedure for Determining Off-Road Vehicle Fuel Efficiency
- Status
  - Project Not Started
  - Was Scheduled to Begin in February 1998
  - Funding Being Redirected

JTEV Support

- Objective
  - Provide Support to JTEV at Various Demonstrations and Presentations.
  - Maintain Operational Capability
- Status
  - All Activities Were Supported as Requested

AeroVironment Inc.

Fuel Consumption and Efficiency Test

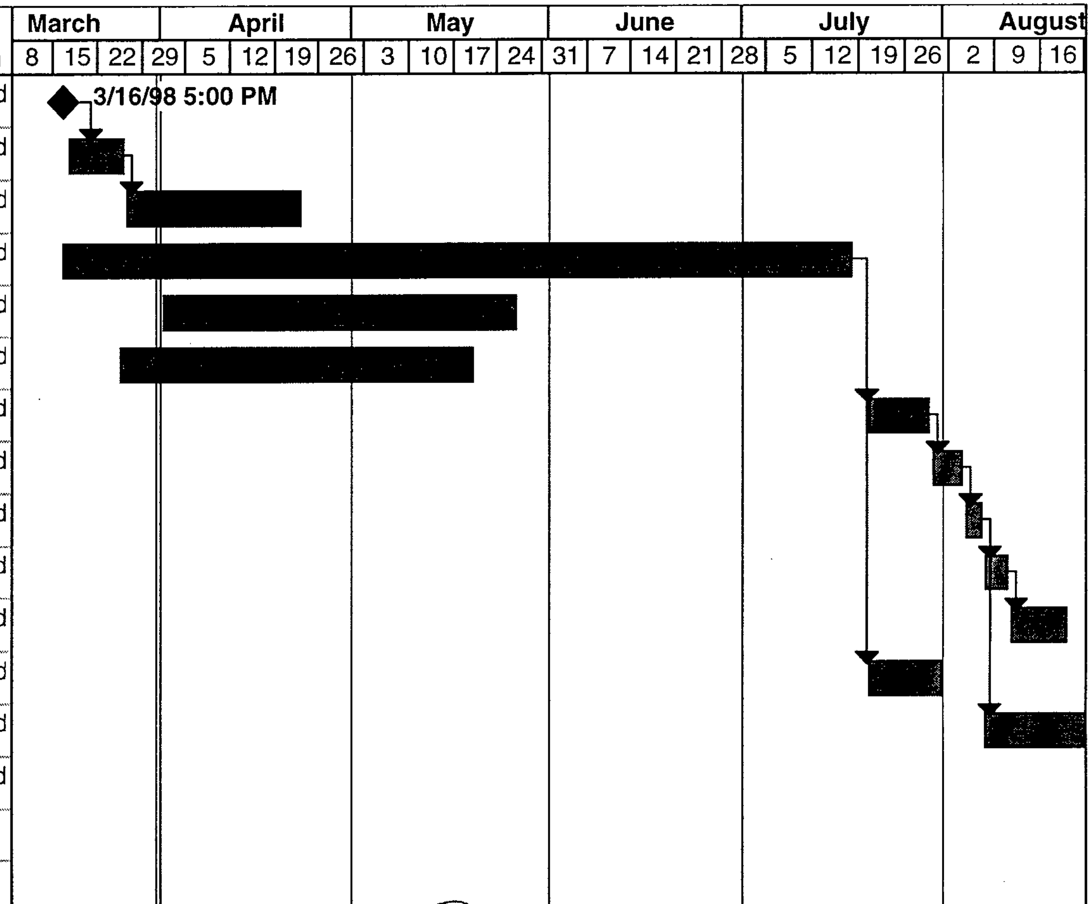
- Objective
  - Operate JTEV on Prescribed Course at APG to Determine Fuel Consumption
  - Determine Drive Component Efficiencies
- Status
  - Scope of Work and Schedule Being Developed
  - Requires Repair of Vehicle, Refinement of Algorithms and Instrumentation
  - Will Be Funded from Redirected Project Sources

Redirect #177K → proposal → submit to Jeff Bradel

AeroVironment Inc.

JTEV Fuel & Efficiency Test

ID	Task Name	Duration
1	Start of Work Authorization	0d
2	Ship Vehicle to AV	7d
3	Repair and Refurbish	20d
4	Algorithm Refinement/Test	90d
5	Contract with APG	40d
6	Prepare for test	40d
7	Ship vehicle to APG	8d
8	Prepare vehicle at APG	3d
9	Perform Test	3d
10	Restore vehicle	2d
11	Return vehicle to AV	7d
12	Prepare algorithm report	10d
13	Prepart test report	20d
14	Submit Reports	0d
15		
16		



Schedule has already slipped

AeroVironment Inc.

Project Funding Level

1996 Programs

- Two Speed Transmission — $92K
- Battery Testing — $100K
- JTEV Support and Management — $167K

1997 Programs

- Algorithm Refinement — $65K
- Fuel Efficiency Test Procedure — $91K

New Programs

- Fuel Consumption Efficiency Test — TBD

→ awaiting a decision from Jeff Bradel.

4/1/98 Presentation to DARPA Program Review

Heavy-Duty Hybrid Electric Vehicle Industry Analysis

Items for Discussion

- Project Overview
- Progress to Date
- Findings to Date
- Next Steps
- Feedback

What component of technology likely to succeed?
5 year time frame?
Where is the industry ahead in which country?
Which technology & components have a good track record?

Project Overview

- Assess state of technology for HDHEVs
  - Full Vehicles
  - Components
- Evaluate military benefits
  - Physical attributes
  - Cost benefits
  - Fuel diversification

Project Overview

- Identify key players, critical trends, and potential market pathways
  - Emission standards
  - Market incentives and command-and-control strategies
  - Early adopters
- Evaluate competing technologies
  - LNG and diesel configurations

Get copy of VDLP from DARPA -- Predecessor to CHPS Program. Report is titled "All Electric Combat Vehicle."

Progress to Date

- Reviewing technical literature
- Reviewing demonstration programs
- Briefings with HEV manufacturers
- Attending conferences, seminars, workshops
- Arranging site visits and interviews
- Compiling inventory database

Findings to Date

- HEV technology is developing at an accelerated pace world wide.
  - 60 heavy-duty electric and hybrid vehicle models
  - 15 different propulsion systems
  - 10 fuel cells
  - 10 ultra-capacitors
  - dozens of battery manufacturers
- Large number of new entries in HEV field
  - Universities, government agencies, research facilities, car manufacturers, electronic companies, consortiums, nat'l labs

Is there an engine optimized as a hybrid APU?

Findings to Date

CALSTART — DARPA

- Large technology overlaps and fragmented knowledge of related technologies
  - Little inter-technology communication
  - No standardization
- Europe and Japan are in the forefront of HEV technology research and development
  - Under-reported in U.S. literature

Next Steps

CALSTART — DARPA

- Interviews and site visits with manufacturers, nat'l labs, regulators, transit agencies, researchers
- Continue vehicle and component inventory database
- Expand contact network and knowledge through conferences, literature, workshops, etc.

Who is the report for?

A) Component suppliers — better supply military market

RR ok w/ sensitivity analysis — don't want to see specific estimates,

RR: C/S should become the source on hybrids.
Not what DARPA wants — but that's OK.

Audience: A) Potential repeat customers for C/S?
~~A)~~ Component developers; ~~B)~~ veh. mfgers.
B) Govt. ~~Agencies~~ — policymakers (not blatantly — but should tell (direct the govt. what to do). Serve as a resource for them. Help govt w/ funding programs? Maybe come up w/ ideas on what should be done. Identify some opptys.

Report should have a disclaimer on front page that the report doesn't represent DARPA's position.

7-9 months from today's date ~~from~~ is OK.

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Completed Projects

PROGRAMMABLE DC CONTROLLER

Project Manager: ***Jefferson Programmed Power***
CS-AR94-02

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	DATE COMPLETE	DARPA FUNDS EXPENDED
1	Design complete	72,000		1	10/10/95	10/25/95	72,000
2	CPU Logic Board operational	65,000	80,000	2	1/10/96	1/11/96	65,000
3	1st prototype controller test	50,000	60,000	3	4/10/96	4/17/96	58,300
4	Final report	30,000	77,000	4	6/30/96	9/20/96	21,700
	CS-AR94-02 TOTALS	217,000	217,000				217,000

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RUNNING CHASSIS II

Project Manager: ***Amerigon Incorporated***
CS-AR94-01

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Initiate work	200,000	460,000	1	11/14/95	11/21/95		75,000
2	Complete breadboard designs of drive train, running chassis, steel space frame	175,000	200,000	2	12/31/95	12/15/95		103,222
3	Fabricate EV4 & BEV prototype parts. Complete build of EV4	125,000	0	3	3/31/96			270,000
4	Complete all BEV tests. Revise tools for EV4 and BEV	40,000	15,000	4	6/30/96	7/8/96		
5	Complete build EV4. Complete EV4 vehicle tests.	0	0	5	9/30/96	9/30/96		
6	Complete and begin tests 1st productionized drive train.	0	0		12/31/96	12/31/96		36,000
7	Complete finite element Analysis. Complete design BEV running chassis.	0	0		3/30/97	4/30/97		71,778
8	Complete build/test 4 alumn BEV's w/o body panels – 2 w/welded & bonded frames. Build/test 5 productionized drive trains. Complete comparative chassis analysis and final report.	160,000	45,000	6	6/30/97	7/30/97		144,000
		700,000	**720,000**				**4,098,410**	**700,000**

Match funds were not fully reported during the project. Byron Kwan, Controller, closed the project accounting records with Amerigon's costs at $4,098,410.

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NAVAL AIR STATION ALAMEDA: PROJECT HATCHERY NORTH

Project Manager: ***CALSTART***
CS-AR94-09A

NAVAL AIR STATION ALAMEDA: CLUSTER PLANNING

Project Manager: ***CALSTART***
CS-AR94-09B

MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	DARPA FUNDS EXPENDED
Contract Award. Initiate Site Analysis Purchase Equipment	125,000	40,000	0	7/24/95	7/24/95	125,000
Final lease negotiations. Open Incubator.	75,000	15,000	1	12/30/95	7/23/96	75,000
Complete Required facility Up-fits.	75,000	10,000	2	3/30/96	3/30/97	75,000
Develop strategic marketing materials.	50,000	20,000	3	6/30/96	1/30/97	50,000
Complete NAS facilities Assessment.	50,000	15,000	4	9/30/96	On-going from 95	50,000
Facilitate lease arrangements with Cluster firms	50,000	25,000	5	12/30/96	12/30/96	50.000
Final Report	0	25,000	6	3/30/97	9/30/97	
	400,000	150,000				400,000

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SAFE ELECTROMECHANICAL BATTERIES FOR EVS

Project Manager: ***Rocketdyne***
CS-AR95-05

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	Containment ring design	50,000	552,000	1	12/31/96	12/31/96	552,000	63,472
2	Containment ring fabrication	75,000	77,000	2	3/30/97	3/30/97	77,000	97,463
3	Assembly checkout/test	100,000	77,000	3	6/30/97			12,221
4	Final report	34,500	77,000	4	9/30/96			
		259,500	**783,000**				**629,000**	**173,156**

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HEAVY FUEL INJECTOR

Project Manager: ***Engine Corporation of America***
CA-DARO-03

	MILESTONES	DARPA	MATCH	QTR	DATE DUE	COMPLETE	MATCH FUNDS EXPENDED	DARPA FUNDS EXPENDED
1	1.0 Completion and submission of program plan	122,500	0	1	3/30/97	7/1/97		122,500
2	1.1 Overall Engine Design, 1.2 Engine Thermal Cycle Analysis,1.1 Coordination of Analytical Effort with FEV, 2.1 ECA Fuel Injector Design,2.2 Fuel Injector Options Assessment, 2.3 Coordinated Fuel Injection Review	122,500	245,000	2	6/30/97	9/30/97	245,000	122,500
	TOTAL	245,000	245,000				245,000	245,000

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ELECTRIC AND HYBRID ELECTRIC VEHICLE DATA ACQUISITION SYSTEM

Project Manager: ***CALSTART***
CS-AR94-12

	MILESTONE	DARPA	MATCH	DATE DUE	COMPLETE	DARPA FUNDS EXPENDED
1	Feasibility Study	50,001		9/30/95	9/30/95	16,271
2	Schematic /housing for keypad/display	16,271		12/31/95	12/31/95	9,957
3	Establish Internet Connection	20,608		3/30/96	2/96	20,608
4	Hardware Test Box for Analog/digital boards	54,077		6/30/96	5/96	54,077
5	DC Converter Schematics Build Prototype.	16,666		9/30/96	12/96	21,700
6	Second PCB Testing CDAS and Installation	51,750		12/31/96	PCB-10/96 Test Begun 11/96	27,387
7	Testing			3/30/97	Not completed	
8	Final Report			6/30/97	3/31/97	
	TOTAL	**150,000**	**0**			**150,000**

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Canceled Projects

OPTIMIZED 30kW TURBINE/FLYWHEEL HYBRID ELECTRIC VEHICLE

Project Manager: ***Rosen Motors***

ALUMINUM RUNNING CHASSIS FOR CIVILIAN USE (RCP-4C)

Project Manager: ***Amerigon Incorporated***

ALUMINUM RUNNING CHASSIS FOR MILITARY USE (ARC4-M)

Project Manager : ***Amerigon Incorporated***

HYBRID ELECTRIC BATTERY

Project Manager: ***Bolder Technologies***
CS-AR94-05

HEAVY-DUTY HYBRID ELECTRIC DRIVE TRAINS

Project Manager: ***Santa Barbara Air Pollution Control District***
CS-AR94-03

	MILESTONE	DARPA	MATCH		DARPA FUNDS EXPENDED
CS-AR94-03	No milestone - program canceled	29,568	9,856		29,568
		29,568	9,856		29,568

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ELECTRIC AIRPORT SHUTTLE BUSES

Project Manager: ***Santa Barbara Air Pollution Control District***

ENERGY MANAGEMENT CONTROLLER

Project Manager: ***Delco Electronics***
CS-AR94-13

	DARPA	MATCH				DARPA FUNDS EXPENDED
CS-AR94-13	18,000					18,000
	18,000	0				18,000

E/HEV MANUFACTURABILITY ASSISTANCE PROGRAM

Project Manager: ***CALSTART***
CS-AR96-04